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COST ALUMINUM STRUCTURES TECHNOLOGY, PHASE III (CAST).(U)

JAN 78 D GOEHLER F33615-76-C-3111

UNCLASSIFIED D180-22807-1 AFFDL-TR-78-7 NL

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18 19 AFFDL-TR-78-7

2 LEVEL II

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CAST ALUMINUM STRUCTURES TECHNOLOGY, PHASE III (CAST).

NH

THE BOEING COMPANY
SEATTLE, WASHINGTON 98124

14 D180-22807-1

11 JAN [redacted] 78

12 135p.

TECHNICAL REPORT AFFDL-TR-78-7

9 Final Report, [redacted] Feb [redacted] – Dec [redacted] 77

10 Donald Goehler

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AIR FORCE WRIGHT AERONAUTICAL LABORATORIES 63211 F
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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Project Engineer,

William R. Johnston

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Actg Prog Mgr, AMS Program Office
Structural Mechanics Division

FOR THE COMMANDER

Holland B. Lowndes

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Structural Mechanics Division

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

CAST, aluminum castings, YC-14 bulkhead, A357 aluminum alloy, allowables, fatigue, durability, damage tolerance, detail design, static loads, stress

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of CAST is to establish the necessary structural and manufacturing technologies and to demonstrate the validate the integrity, producibility, and viability of cast aluminum primary airframe structures.

The baseline design is the AMST prototype YC-14 and the component selected was the Nose Landing Gear Support Bulkhead. (Over)

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Block 20 (Continued)

Detail design activities are described that were aimed at providing a cast bulkhead design for production with no weight penalty and at a minimum of 30% acquisition cost savings.

A detail design was completed that resulted in a 6.5-pound weight savings and an estimated 37.7% cost saving.

FOREWORD

This report was prepared by the Boeing Military Airplane Development Division of the Boeing Aerospace Company, Seattle, Washington under USAF Contract No. F33615-76-C-3111. The contract work was performed under project 486U under the direction of the Air Force Flight Dynamics Laboratory, Advanced Metallic Structures/Advanced Development Program Office, Wright-Patterson AFB, Ohio. A significant portion of the contract is being funded by the Metals Branch of the Manufacturing Technology Division of the Air Force Materials Laboratory. The Air Force Project Engineer is John R. Williamson of the AMS Program Office, Structural Mechanics Division, Air Force Flight Dynamics Laboratories (AFFDL/FBA).

The Boeing Aerospace Company, Military Airplane Development, is the contractor, with Donald E. Strand as Program Manager and Donald D. Goehler as Technical Leader. This phase of the program was conducted by Richard C. Jones assisted by Carlos J. Romero and Christian K. Gunther.

The contractor's report number is D180-22807-1. This report covers work from February 1977 through December 1977.

Previous work conducted on this contract over the period June 1976 to February 1977 has been reported in Technical Report AFFDL-TR-77-36, dated May 1977.

A043 469

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CONTENTS (Continued)

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

TABLES

SECTION I

INTRODUCTION

The purpose of the CAST program is to demonstrate that aluminum castings can be used for primary aircraft structural components. The program goal is to achieve the above with no weight penalty and with a minimum of 30% cost savings. The baseline component selected to demonstrate structural casting capability is the YC-14 body bulkhead at body station 170. This is the body nose bulkhead which provides forward support for the nose landing gear and nose gear door, carries cabin pressure on upper segment, and provides support for the nose radome.

The Phase III objective is to complete and release a detail design of the cast bulkhead and the machined bulkhead assembly that meets or exceeds the CAST program goals.

The detail design phase (Phase III) consists of: production drawing preparation to include design layouts for review, analysis, and completion of final production drawings; strength and stability analysis; fatigue and damage tolerance analysis; effects of defects analysis; detail design weight analysis; preparation of detailed projected cost estimates; final review, approval, and release of the production detail design bulkhead; an update of the baseline component data originally released in Phase I; and an on-site review covering Phase III activity.

The detail design of the transition structure and test fixtures will be prepared and released in Phase V, "Structural Test and Evaluation."

This report summarizes the work completed during Phase III.

SECTION II

DETAIL DESIGN

The Phase III Detail Design efforts continued on from Phase I Preliminary Design. The detail design of the production cast bulkhead was based on the final cast bulkhead concept and the preliminary design criteria established in Phase I. Efforts in this phase were on detail drawing completion, analysis, and release to manufacturing, plus an update of the baseline component data.

1. DESIGN LAYOUT

The first design layout of the body station 170 cast bulkhead was an update of the final approved concept from Phase I (fig. 1). Design features of this concept included the following.

- o A close physical match to the existing bulkhead structure, especially in the areas of interface with adjacent structure. This was to provide continuity of existing load paths and required no revision to the adjacent structure.
- o The single casting replaced all parts of the original baseline component plus the crosswise slanted beam at WL 150.
- o Machining of casting is required only for close tolerance contour at skin IML and at nose gear fitting interface locations.
- o Bulkhead web of minimum castable thickness and with the upper pressurized section made in a corrugated form replacing the original stiffened web. A transition section to the lower stiffened web segment is located between WL's 124.6 and 130.

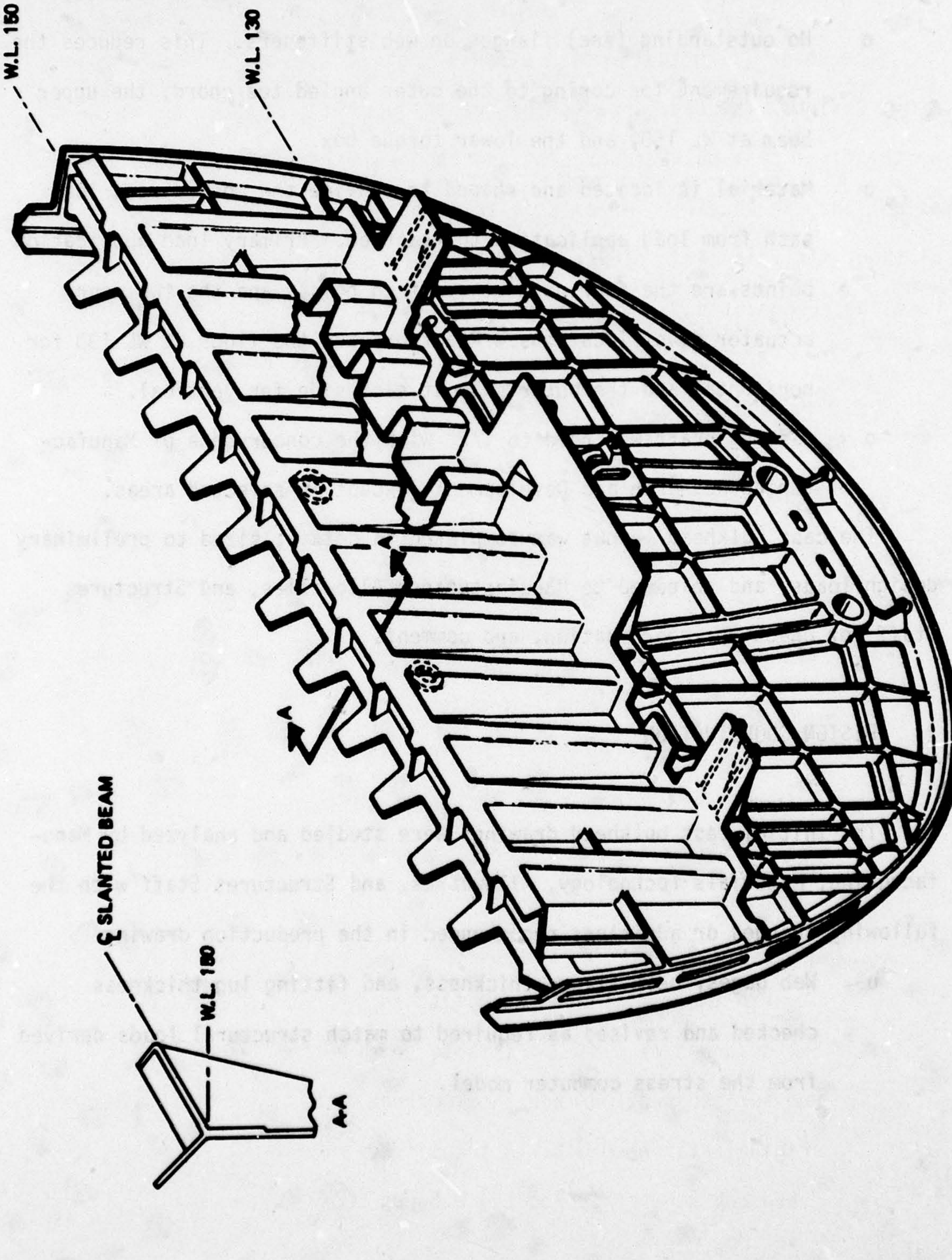


Figure 1 . Station 170 Body Bulkhead From Phase I

- o Below WL 124.6, the web stiffeners extend both fore and aft of the web. The reduced height of the stiffeners from the web provides better castability and reduced amount of draft material.
- o No outstanding (zee) flanges on web stiffeners. This reduces the requirement for coring to the outer angled tee chord, the upper beam at WL 150, and the lower torque box.
- o Material is located and shaped to provide the most direct load path from load application to reaction. Primary load application points are the four nose gear attach points and the two door actuator pivot locations. Reactions are the floor at WL 130 for horizontal and the outer skin at each side for vertical.
- o Casting draft was held to 1/2° with the concurrence of Manufacturing Research and Development, except in selected areas.

The cast bulkhead layout was completed in detail, sized to preliminary design loads, and released to Manufacturing, Allowables, and Structures Staff for checking, coordination, and comments.

2. DESIGN COORDINATION

The initial cast bulkhead drawings were studied and analyzed by Manufacturing, Materials Technology, Allowables, and Structures Staff with the following changes or additions recommended in the production drawing.

- o Web gages, beam flange thickness, and fitting lug thickness checked and revised as required to match structural loads derived from the stress computer model.

- Added integral cast-on test coupons for mechanical property testing. Located preproduction test coupons to be excised and tested for mechanical properties.
- The chord casting configuration was revised to remove the step in the parting plane around the periphery of the bulkhead. This reduced cost of the pattern with no increase in machining cost.
- A cross beam extending outboard and upward from the lower boss for the door actuator pivot to the outer chord was revised to be horizontal. This beam would have crossed from one mold flask to another at a very flat angle, requiring extremely close tolerance in mold assembly. The revision located the beam entirely within one flask.
- Recesses were added in the large boss at approximately RBL 8.7 and WL 120. These were added for reduction of casting thickness in an area of low stress.

3. DRAWING RELEASE

After completion of drawing revisions resulting from design coordination, the drawings were rechecked and approved by Stress, Design, and Project. Copies of the drawing were then released to Manufacturing organizations, Structures Test, and Structures Staff groups including Stress, Fatigue, Weights, and Allowables.

4. PRODUCTION DRAWINGS

The production bulkhead casting drawing, 162-00017, is a four-sheet drawing on mylar with a half-size rear view and full-size section views.

The production bulkhead assembly drawing, 162-00018, is a four-sheet drawing made from "brown line" reproducible copies of the bulkhead casting drawing. This drawing deletes the basic casting dimensioning and adds machining dimensions, bushings, inspection requirements, and finishes.

a. Bulkhead Casting

Drawing 162-00017 Sheets 1 through 4 were reduced to document size and are included for reference only (pages 7 through 10).

b. Bulkhead Assembly

Drawing 162-00018 Sheets 1 through 4 were reduced to document size and are included for reference only (pages 11 through 14.

6	5	4

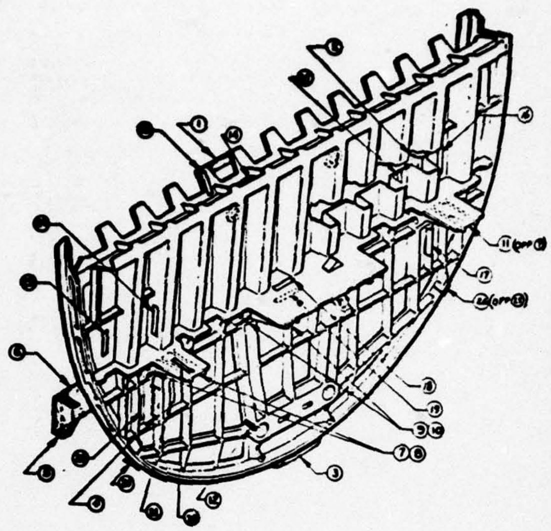


TABLE 1

SPECIMEN	DAS (MAX) ([illegible])	ASTM-B[illegible] COUPON CONFIG
1		FLAT
2		FLAT
3		ROUND
4		FLAT
5		ROUND
6		FLAT
7		ROUND
8		
9		
10		
11		
12		ROUND
13		FLAT
14		
15		
16		
17		
[illegible]		
[illegible]		
[illegible]		
[illegible]		
[illegible]		
[illegible]		
[illegible]		
[illegible]		FLAT

MECHANICAL PROPERTY TEST COUPON INFORMATION

1 THRU 6 - INTEGRAL CAST-ON COUPONS
7 THRU [illegible], 11 (OPP 7) & [illegible] LUG SPECIMENS
[illegible] & [illegible] SLANTED BEAM SPECIMENS
[illegible] THRU [illegible] & [illegible] (OPP [illegible]) WEB, FLANGE OR CHORD SPECIMENS
PREPRODUCTION TEST EXCISED COUPONS

MEASURE DENDRITE ARM SPACING (DAS) PER MIL-Y-XXXX (CAST) ACCEPTABLE DAS VALUES ARE LISTED IN TABLE 1.
TEST ALL TENSILE SPECIMENS PER MIL-A-XXXX (CAST).
ALL TENSILE COUPONS SHALL BE PERMANENTLY IDENTIFIED BY CASTING & LOCATION.
ALL EXCESS PORTIONS OF A CASTING WHICH ARE REMOVED DURING THE EXCISION OF TENSILE COUPONS MUST BE PERMANENTLY MARKED FOR IDENTIFICATION.
SEE DRAWING, (SHT 2, 3 & 4) FOR DETAILED LOCATION OF SPECIMENS.

-1	162-00018	CAST PROGRAM	TEST ONLY	[illegible]
[illegible]	NEXT ASSY	USED ON	EFFECTIVITY	[illegible]
	APPLICATION			

6	5	4

3	2	1

NOTES

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE):

[2] DATUM TARGET POINT DIMENSION. GEN'L DWG TOL DOES NOT APPLY

[3] HORIZONTAL DIMENSION TO DATUM PLANE C (RBL .241 REF)

[4] STEP RESULTING FROM CASTING DRAFT

[5] CLASS 1, GRADE B IN CRITICALLY STRESSED AREAS. GRADE C ELSEWHERE PER MIL-A-XXXX. INSPECT PER MIL-A-XXXX SECTION 4. CRITICALLY STRESSED AREAS DEFINED ON DRAWING AS SHOWN: [- - - -].

[6] RAISED .25 LETTERS & NUMBERS (RUBBER STAMP OPTIONAL)

7 DIMENSIONS & TOLERANCES
- EDGE RADII .03 ± .03
- FILLET RADII .25 ± .06
- CORNER RADII .06 ± .06
- DRAFT ANGLE 1/2° MAX

EXCEPT AS NOTED

SEE DIM. & TOL. BLOCK, ZN A-2
BREAK ALL SHARP EDGES .02 MIN

[8] HEAT TREAT T6 PER MIL-A-XXXX, 3.1.8, 3.2.6 & 3.3.5

[9] WELD CORRECTION OF DEFECTS DETECTED PRIOR TO MACHINING IS ALLOWED PER MIL-W-XXXX (CAST)
HEAT TREAT CORRECTED CASTING PER [8]
INSPECT CORRECTED CASTING PER [5]

REV STATUS	
2	A
3	A
4	A

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

D

C

B

A

PARTS LIST

FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	HT TR	FINISH	PT MK	REV LTR
	MIL-W-XXXX (CAST)	PROCESS SPEC							
	MIL-Y-XXXX (CAST)	PROCESS SPEC							
	-1	BULKHEAD CASTING	A4-2	A357 ALUMINUM PER MIL-A-XXXX (CAST)		[8]	F2.10	[6]	

CONTRACT NUMBER F33615-76-C-3111

DWN R.C. JONES 7-11-77

ANGLES ± 1/2°
.03
.010

FASTENER CODES

ST ONLY 1234

THE BOEING COMPANY
CORPORATE OFFICES SEATTLE, WASHINGTON

BULKHEAD CASTING
STATION 170
CAST

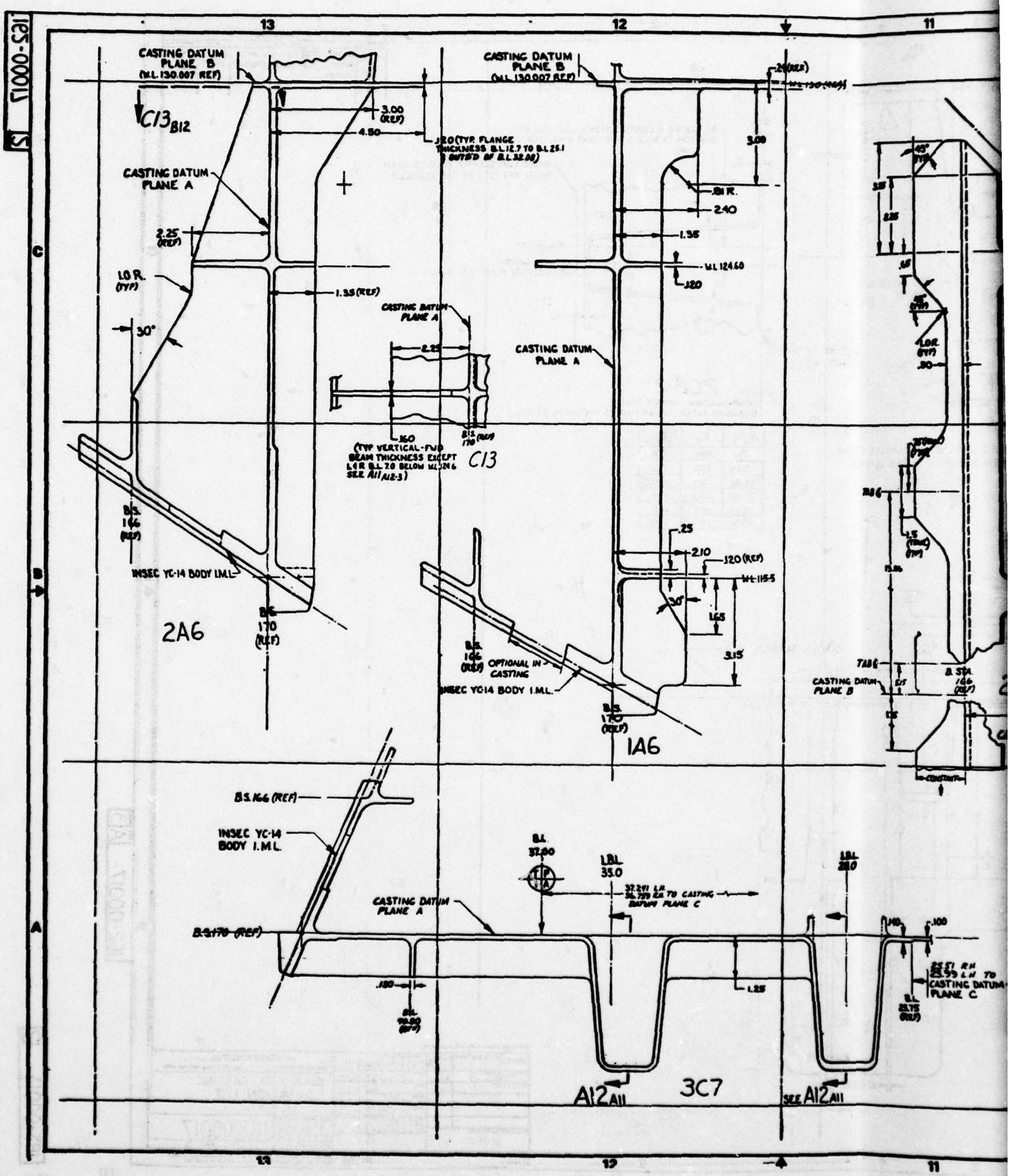
SIZE J CODE IDENT NO 81205 162-00017

SCALE — SH 1 OF 4

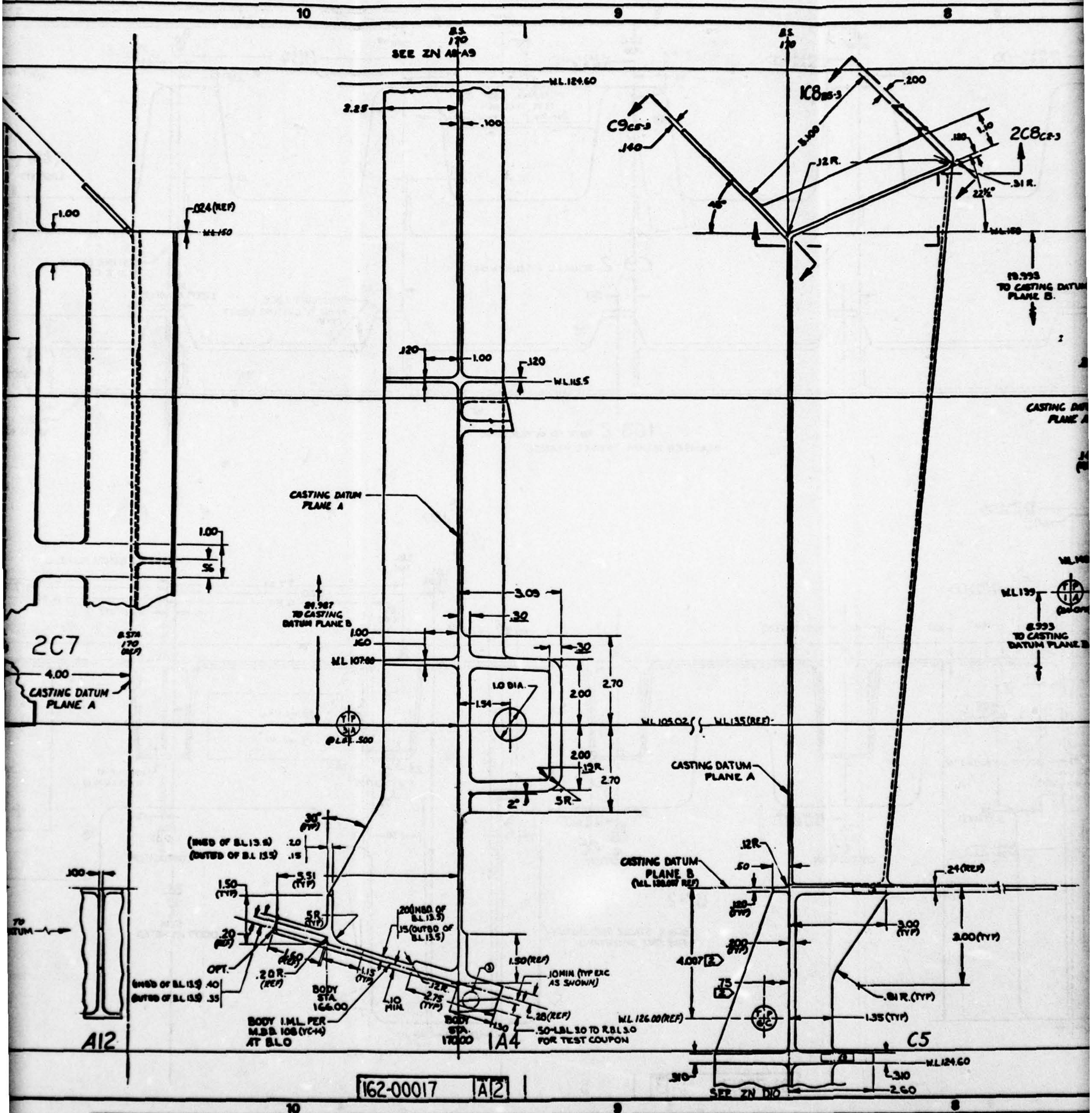
3	2	1

162-00017

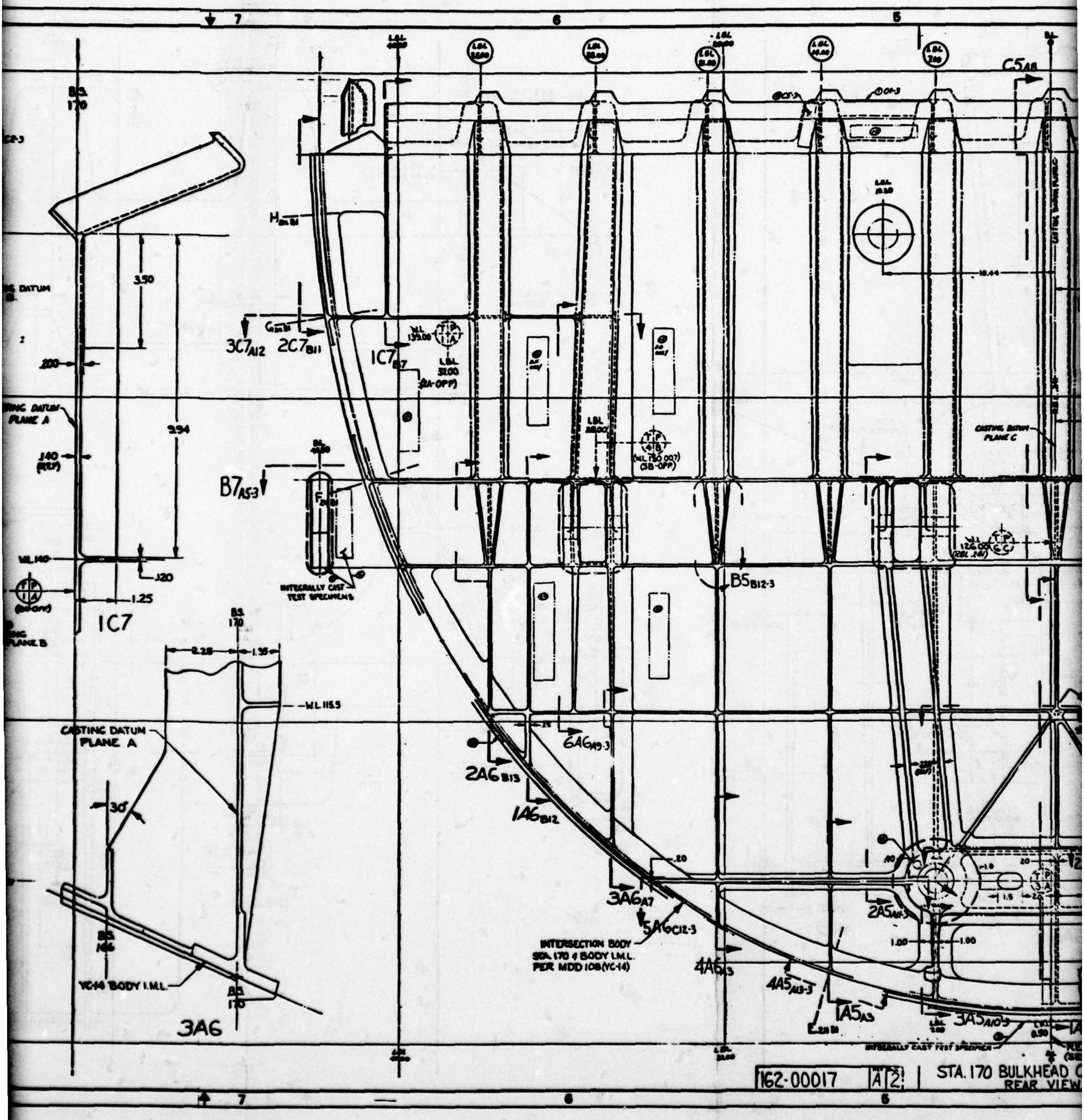
2



CASTING DATUM PLANE B (W.L. 130.007 REF)
C13 B12
CASTING DATUM PLANE A
3.00 (REF)
4.50
.120 (TYP. FLANGE THICKNESS B.L. 12.7 TO B.L. 25.1 & OUTB'D OF B.L. 32.00)
2.25 (REF)
1.0 R. (TYP)
1.35 (REF)
30°
CASTING DATUM PLANE A
2.25
.160 (TYP VERTICAL-FWD BEAM THICKNESS EXCEPT L&R B.L. 7.0 BELOW W.L. 124.6 SEE A11 A12-3)
C13
B.S. 166 (REF)
INSEC YC-14 BODY I.M.L.
B.S. 170 (REF)
2A6
CASTING DATUM PLANE B (W.L. 130.007 REF)
3.00
.81 R.
2.40
1.35
W.L. 124.60
.120
CASTING DATUM PLANE A
.25
2.10
.120 (REF)
W.L. 115.5
30°
1.65
3.15
B.S. 166 (REF)
OPTIONAL IN CASTING
INSEC YC-14 BODY I.M.L.
B.S. 170 (REF)
1A6
CASTING DATUM PLANE B
B. STA. 166 (REF)
B.S. 166 (REF)
INSEC YC-14 BODY I.M.L.
B.L. 37.00
L.B.L. 35.0
CASTING DATUM PLANE A
B.S. 170 (REF)
.180
1.25
L.B.L. 28.0
.100
CASTING DATUM PLANE C
A12 A11
3C7
SEE A12 A11

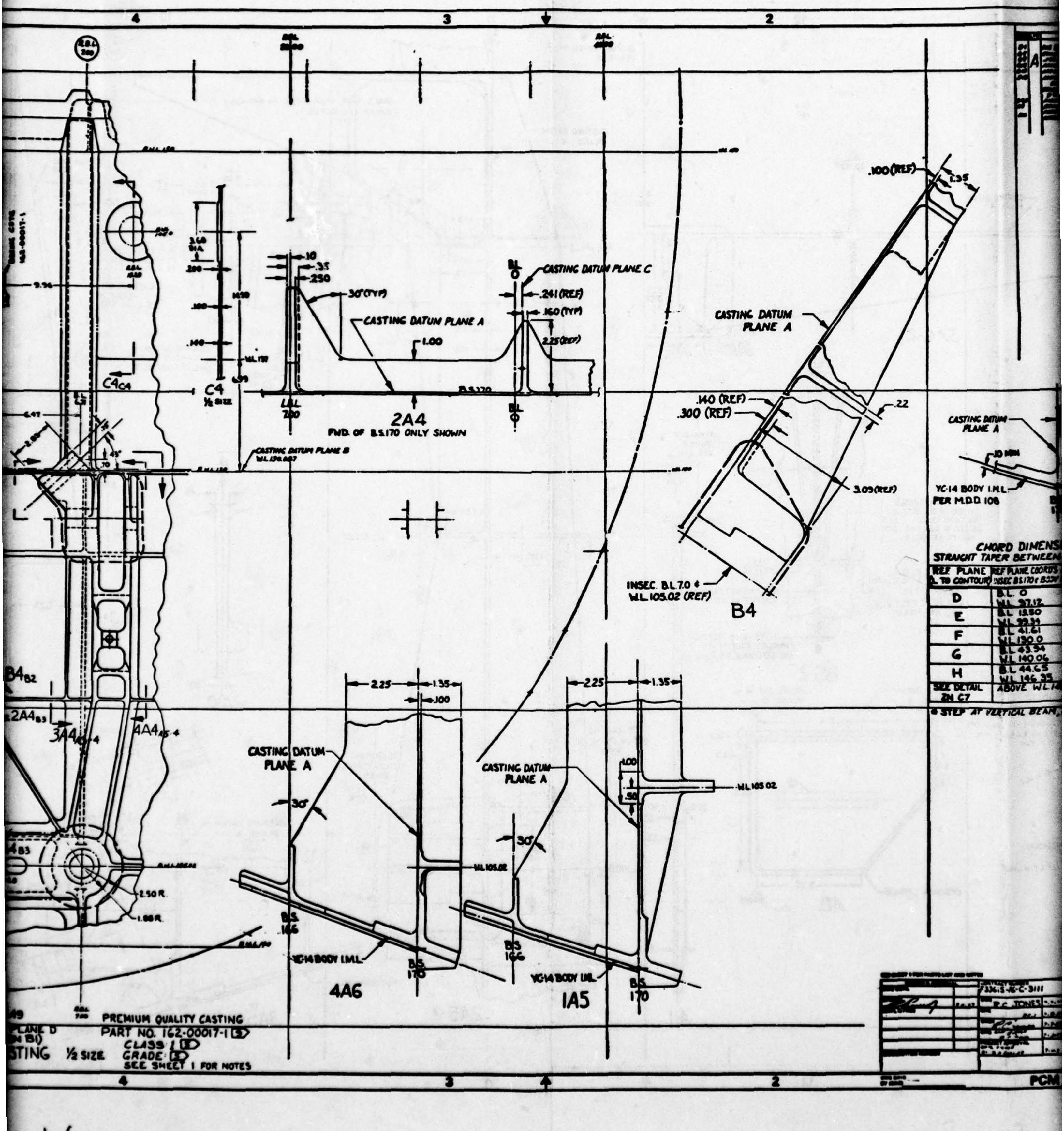

10
9
8
B.S. 170
SEE ZN A8-A9
W.L.124.60
2.25
.100
1C8
C9
.200
.140
2C8
.12R.
.31 R.
22½°
45°
W.L.150
.024(REF)
1.00
19.993 TO CASTING DATUM PLANE B.
.120
1.00
.120
W.L.115.5
CASTING DATUM PLANE A
1.00
.56
3.09
.30
20.967 TO CASTING DATUM PLANE B
1.00
.160
W.L.107.00
.30
2C7
B.STA 170 (REF)
4.00
CASTING DATUM PLANE A
1.0 DIA.
1.54
2.00
2.70
2.00
.12R.
2.70
W.L.105.02
W.L.135(REF)
5R.
2°
W.L.139
8.993 TO CASTING DATUM PLANE B
CASTING DATUM PLANE A
30°(TYP)
(INBD OF B.L.13.5) .20
(OUTBD OF B.L.13.5) .15
3.51 (TYP)
1.50 (TYP)
5R. (TYP)
.20 (REF)
OPT.
.20R. (REF)
.60 (REF)
(INBD OF B.L.13.5) .40
(OUTBD OF B.L.13.5) .35
.20(INBD OF B.L.13.5)
.15(OUTBD OF B.L.13.5)
1.15 (TYP)
.10 MIN
.12R.
2.75 (TYP)
1.50(REF)
.10MIN (TYP EXC AS SHOWN)
.28(REF)
.50-L.B.L.3.0 TO R.B.L.3.0 FOR TEST COUPON
BODY STA. 166.00
BODY STA. 170.00
BODY I.M.L. PER M.B.B. 108 (YC-14) AT B.L.0
.100
A12
1A4
.12R.
CASTING DATUM PLANE B (W.L.138.007 REF)
.60
.120 (TYP)
.24(REF)
3.00 (TYP)
3.00(TYP)
.200 (TYP)
4.007
.75
.81 R.(TYP)
W.L.126.00(REF)
1.35(TYP)
C5
W.L.124.60
.310
.310
2.60
SEE ZN D10
162-00017 A 2

2

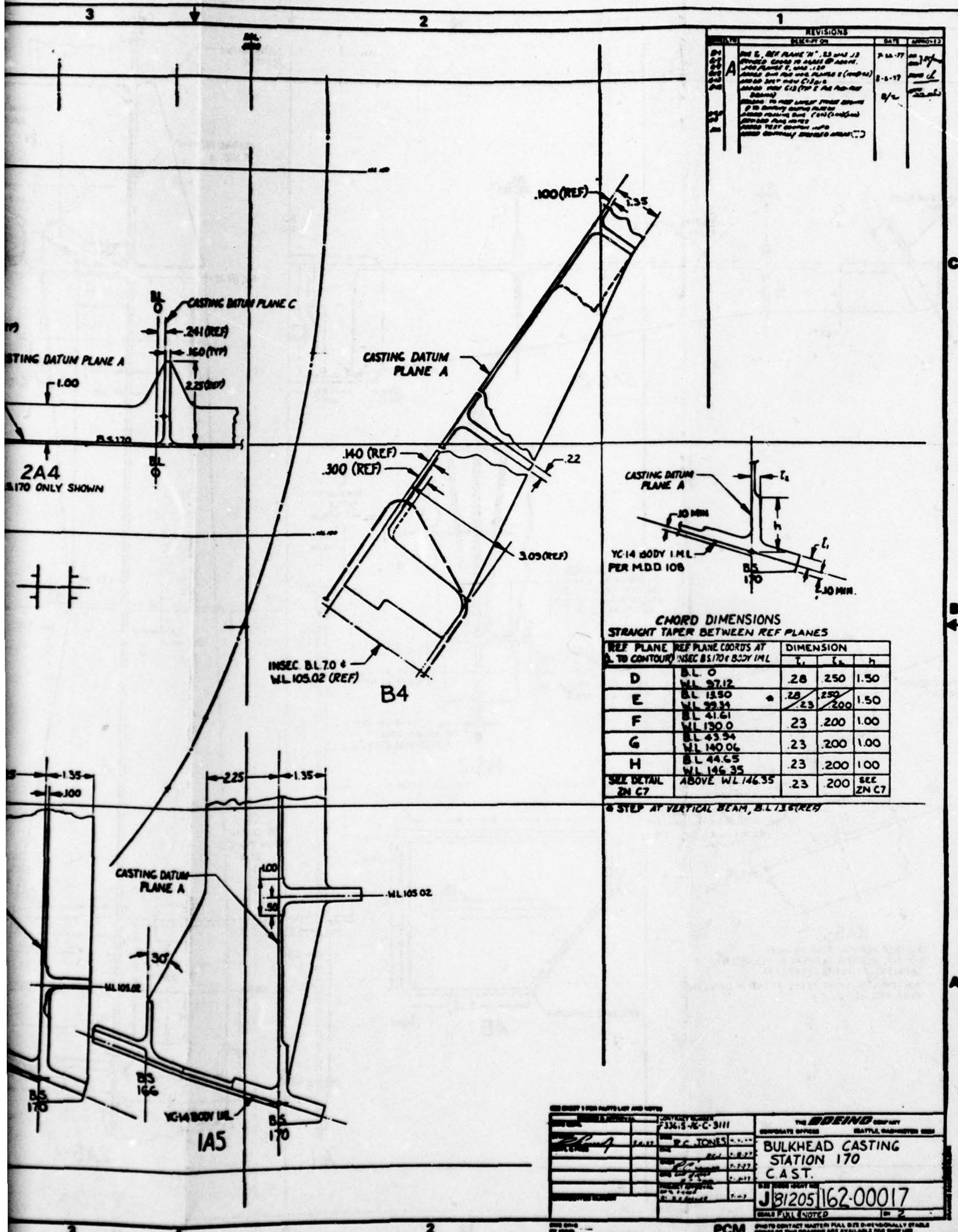


1C7
3AC7
3A6
CASTING DATUM PLANE A
YC-14 BODY I.M.L.
INTEGRALLY CAST TEST SPECIMENS
INTERSECTION BODY STA. 170 & BODY I.M.L. PER MDD 108 (YC-14)
3C7 A12
2C7 B11
1C7 B7
B7 A5-3
B5 B12-3
6A6 A9-3
2A6 B13
1A6 B12
3A6 A7
5A6 C12-3
4A6 A3
4A5 A13-3
1A5 A3
2A5 A11-3
3A5 A10-3
C5 A8
CASTING DATUM PLANE C
INTEGRALLY CAST TEST SPECIMEN
162-00017
A 2
STA. 170 BULKHEAD C
REAR VIEW

3


C4
1/2 SIZE
2A4
FWD. OF B.S.170 ONLY SHOWN
CASTING DATUM PLANE A
CASTING DATUM PLANE C
CASTING DATUM PLANE B W.L.170.687
.241 (REF)
.160 (TYP)
2.25 (REF)
30°(TYP)
1.00
.100 (REF)
1.35
.140 (REF)
.300 (REF)
.22
3.09 (REF)
INSEC. B.L.7.0 ¢ W.L.105.02 (REF)
B4
2.25
1.35
.100
4A6
1A5
W.L.105.02
YC14 BODY I.M.L.
B.S. 166
B.S. 170
2.50 R.
1.88 R.
B4B2
2A4B3
3A4
4A4
C4C4
YC-14 BODY I.M.L. PER M.D.D. 108
CHORD DIMENS
STRAIGHT TAPER BETWEEN
REF. PLANE
D
E
F
G
H
SEE DETAIL ZN C7
B.L. 0
W.L. 97.12
B.L. 13.50
W.L. 99.39
B.L. 41.61
W.L. 130.0
B.L. 43.94
W.L. 140.06
B.L. 44.65
W.L. 146.35
ABOVE W.L.
STEP AT VERTICAL BEAM
PLANE D
STING 1/2 SIZE
PREMIUM QUALITY CASTING
PART NO. 162-00017-1
CLASS 1
GRADE
SEE SHEET 1 FOR NOTES
F33615-76-C-3111
R.C. JONES
PCM

4



CHORD DIMENSIONS
STRAIGHT TAPER BETWEEN REF PLANES

REF PLANE (⊥ TO CONTOUR)	REF PLANE COORD'S AT INSEC B.S. 170 ¢ BODY IML	DIMENSION		
		t_1	t_2	h
D	B.L. 0 W.L. 97.12	.28	.250	1.50
E	B.L. 13.50 W.L. 99.34 *	.28 / .23	.250 / .200	1.50
F	B.L. 41.61 W.L. 130.0	.23	.200	1.00
G	B.L. 43.94 W.L. 140.06	.23	.200	1.00
H	B.L. 44.65 W.L. 146.35	.23	.200	1.00
SEE DETAIL ZN C7	ABOVE W.L. 146.35	.23	.200	SEE ZN C7

* STEP AT VERTICAL BEAM, B.L. 13.5 (REF)

F33615-76-C-3111

R.C. JONES

THE BOEING COMPANY

BULKHEAD CASTING
STATION 170
C.A.S.T.

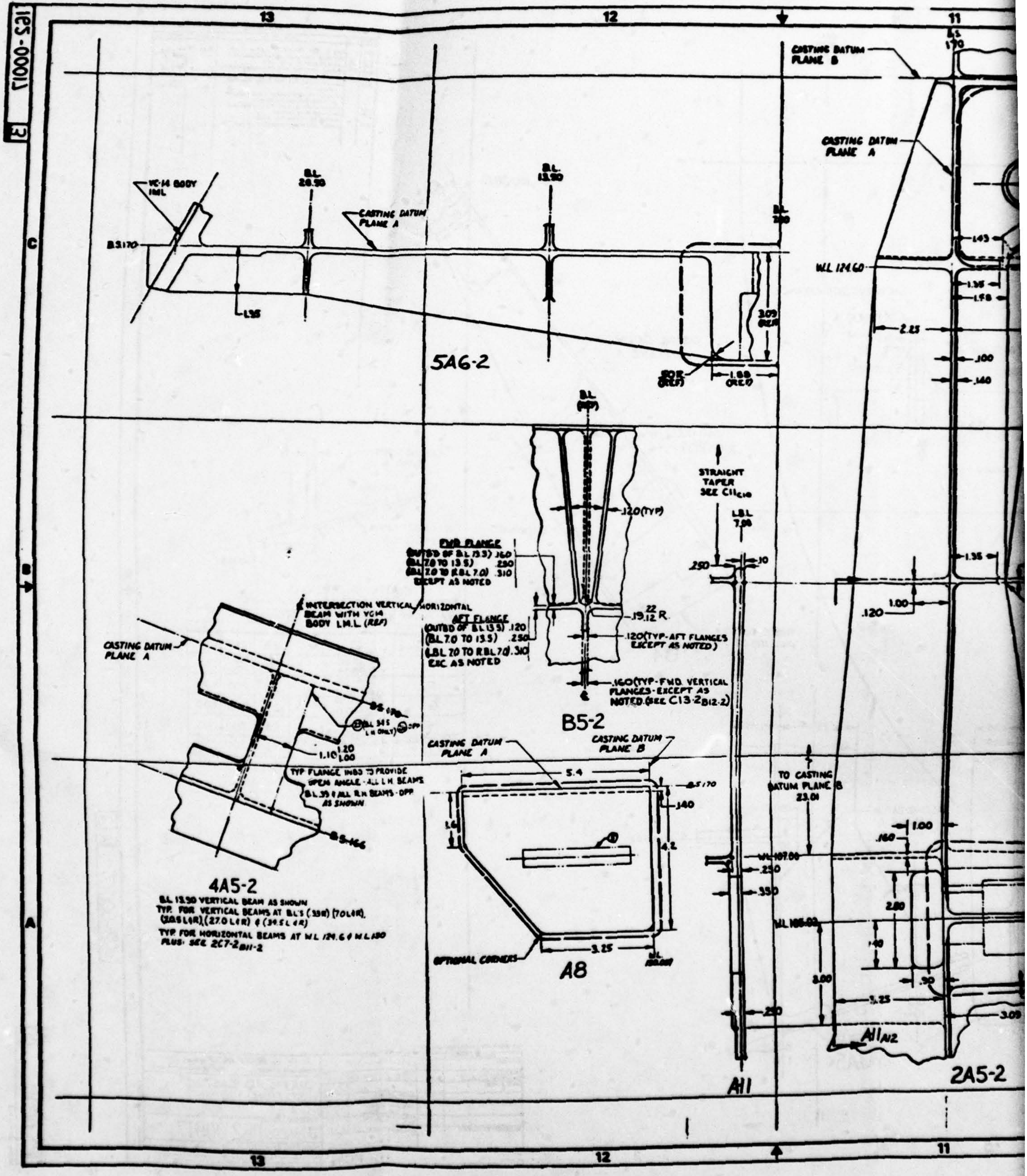
J 81205 162-00017

SCALE FULL & NOTED SH 2

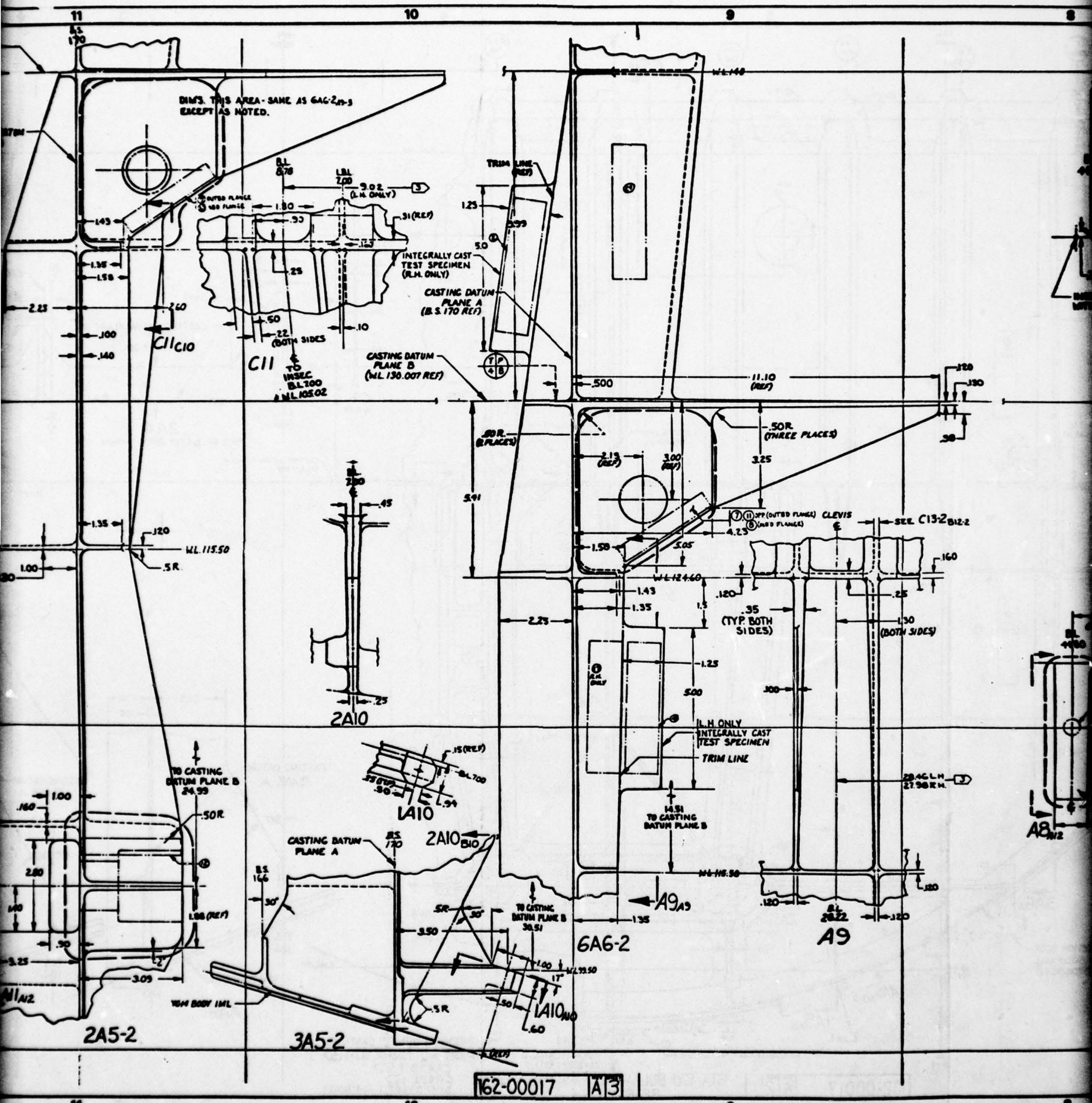
PCM

9

5

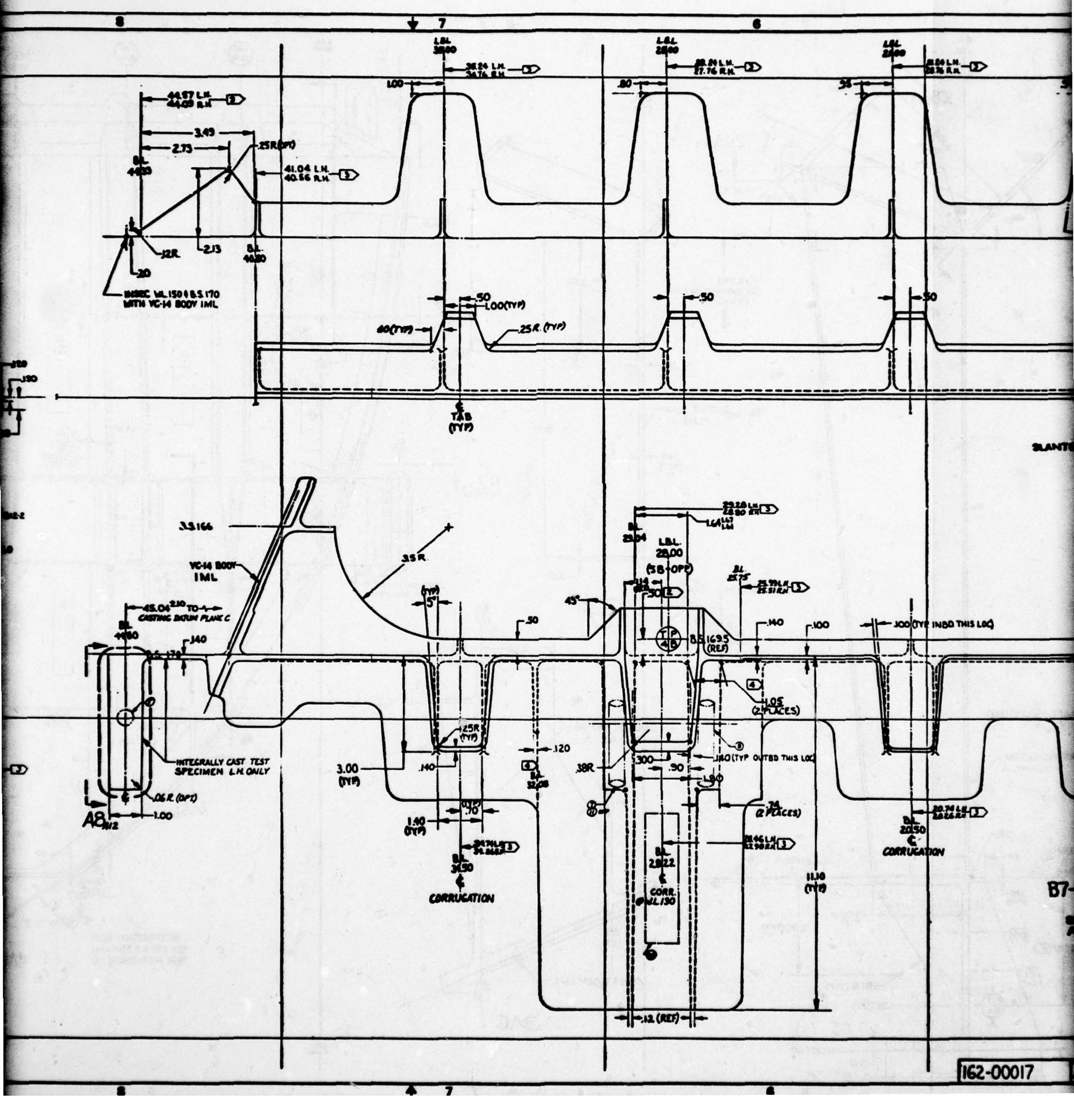


1C52-00017
13
12
11
CASTING DATUM PLANE B
CASTING DATUM PLANE A
VC-14 BODY IML
B.L. 20.50
B.L. 13.50
B.L. 7.00
B.S.170
1.35
5A6-2
B.L. (REF)
.120(TYP)
STRAIGHT TAPER SEE C11
L.B.L. 7.00
FWD FLANGE
EXCEPT AS NOTED
AFT FLANGE
.120(TYP-AFT FLANGES EXCEPT AS NOTED)
.160(TYP-FWD. VERTICAL FLANGES-EXCEPT AS NOTED.(SEE C13-2 B12-2)
B5-2
INTERSECTION VERTICAL HORIZONTAL BEAM WITH VC14 BODY I.M.L (REF)
TYP FLANGE INBD TO PROVIDE OPEN ANGLE - ALL L.H. BEAMS
4A5-2
B.L. 13.50 VERTICAL BEAM AS SHOWN
TYP. FOR VERTICAL BEAMS AT B.L'S
TYP. FOR HORIZONTAL BEAMS AT W.L. 124.6 & W.L. 180
PLUS: SEE 2C7-2 B11-2
5.4
3.25
4.2
.140
OPTIONAL CORNERS
A8
TO CASTING DATUM PLANE B 23.01
W.L. 107.00
W.L. 124.60
2.25
1.00
.120
.250
.350
2.80
3.00
3.25
3.09
A11 A12
A11
2A5-2
A
B
C

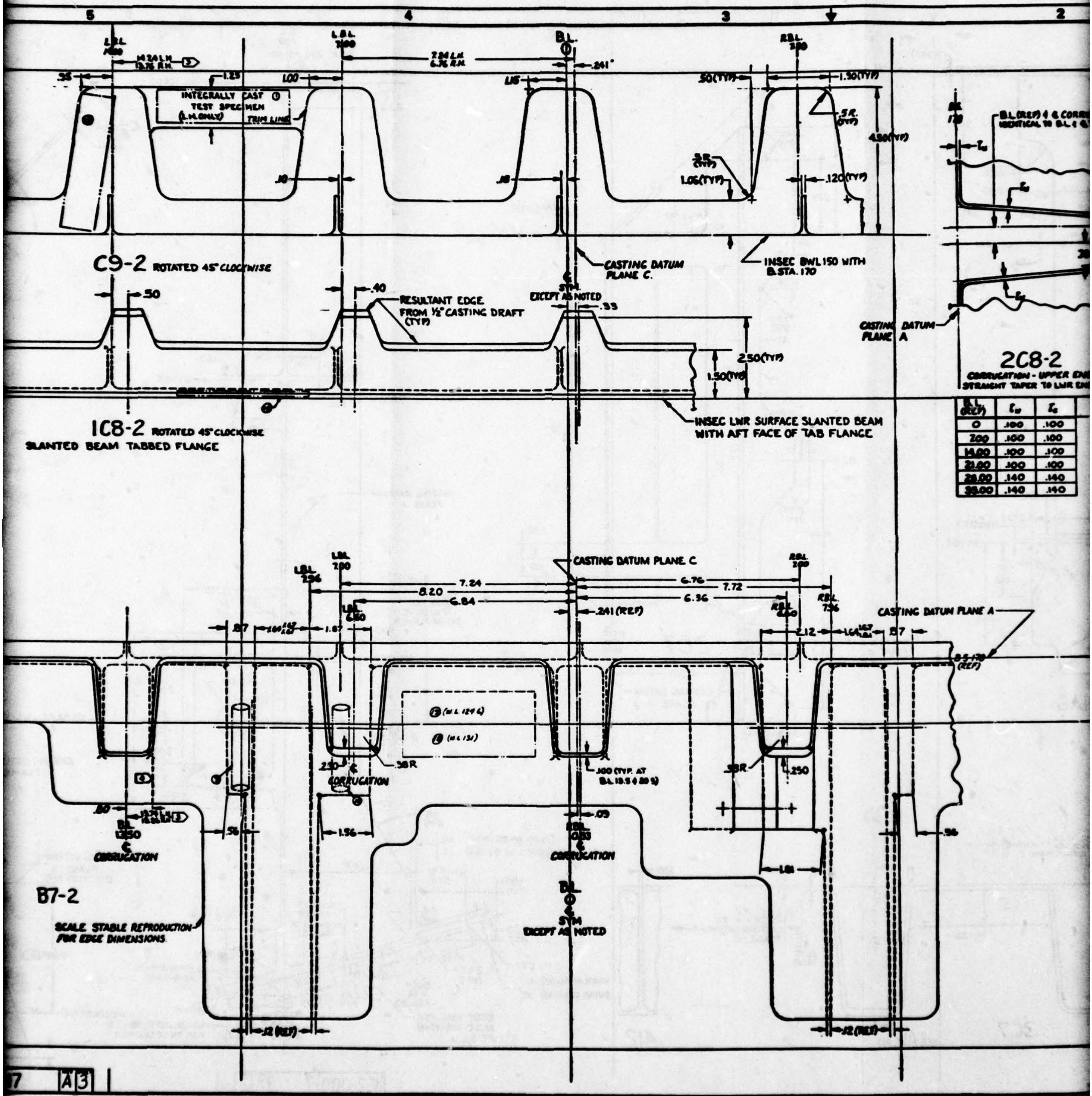


162-00017 A 3

2

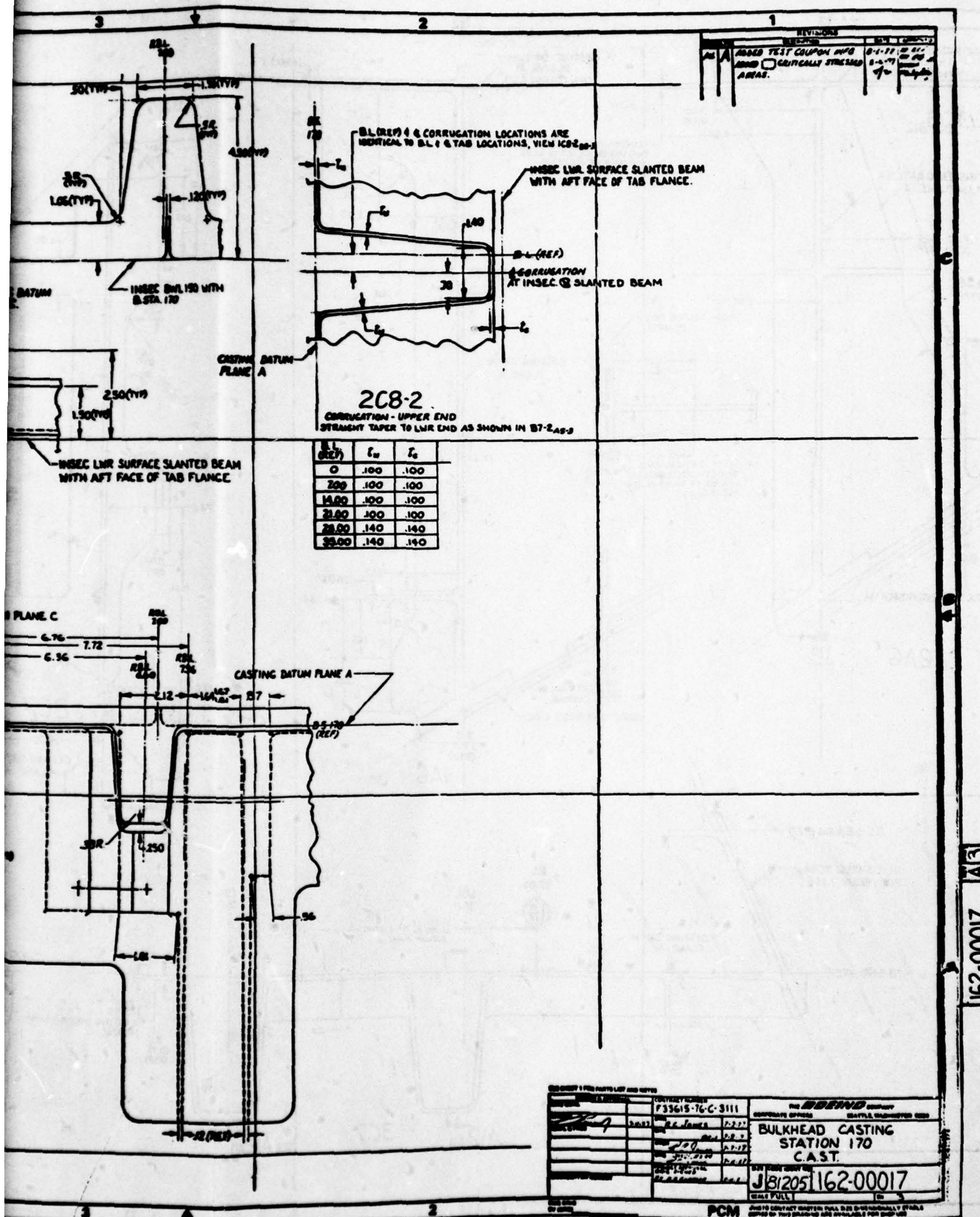


8
7
6
L.B.L. 28.00
3.49
2.73
.25R(OPT)
41.04 L.H.
40.56 R.H.
2.13
.12R
.20
INSEC. W.L.150 & B.S.170 WITH YC-14 BODY IML
.50
1.00(TYP)
.60(TYP)
.25R. (TYP)
TAB (TYP)
SLANTE
3.S.166
3.5 R.
YC-14 BODY IML
45.04
CASTING DATUM PLANE C
.140
.170
.50
45°
(5B-OPT)
.30
B.S.169.5 (REF)
.140
.100
.100 (TYP INBD THIS LOC)
1.05 (2 PLACES)
INTEGRALLY CAST TEST SPECIMEN L.H. ONLY
.06 R. (OPT)
1.00
A8
3.00 (TYP)
.140
.120
.38R
.300
.90
.180 (TYP OUTBD THIS LOC)
1.40 (TYP)
.70
.74 (2 PLACES)
CORRUGATION
CORR. @ W.L.130
11.10 (TYP)
.12 (REF)
B7-
162-00017



B.L. (REF)	t_w	t_c
0	.100	.100
7.00	.100	.100
14.00	.100	.100
21.00	.100	.100
28.00	.140	.140
35.00	.140	.140

4



B.L. (REF)	t_w	t_c
0	.100	.100
7.00	.100	.100
14.00	.100	.100
21.00	.100	.100
28.00	.140	.140
35.00	.140	.140

5

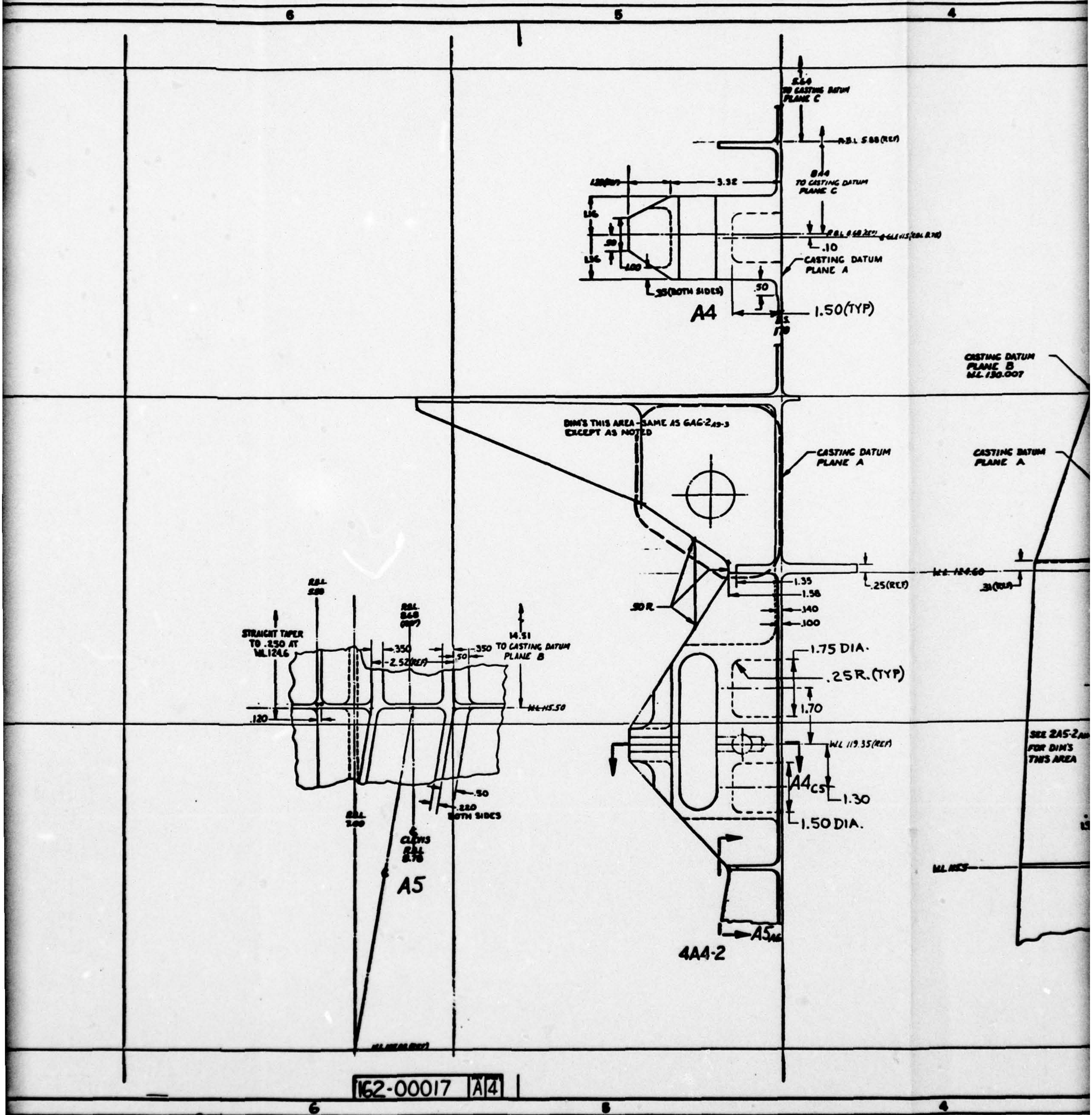
9 8 7

C

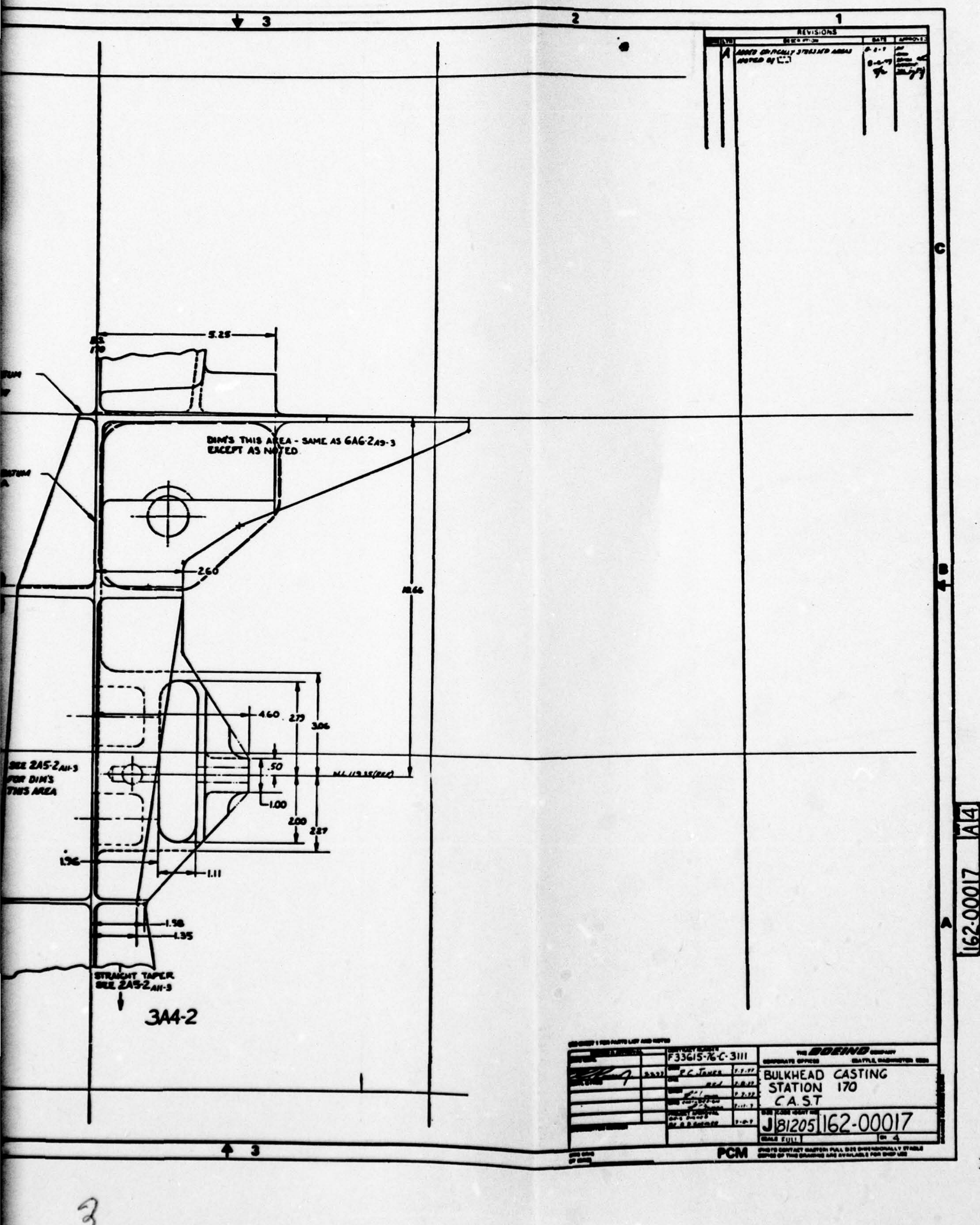
B

A

9 8 7



TO CASTING DATUM PLANE C
3.32
TO CASTING DATUM PLANE C
.10
CASTING DATUM PLANE A
.35(BOTH SIDES)
.50
A4
1.50(TYP)
CASTING DATUM PLANE B
DIM'S THIS AREA - SAME AS 6A6-2 EXCEPT AS NOTED
CASTING DATUM PLANE A
CASTING DATUM PLANE A
1.35
1.58
.140
.100
.25(REF)
STRAIGHT TAPER TO .250 AT WL 124.6
.350
2.52(REF)
.350
.50
14.51 TO CASTING DATUM PLANE B
.120
1.75 DIA.
.25R.(TYP)
1.70
SEE 2A5-2 FOR DIM'S THIS AREA
.50
.220 BOTH SIDES
A4
1.30
1.50 DIA.
A5
A5
4A4-2
162-00017 A 4
6
5
4


REVISIONS
DIM'S THIS AREA - SAME AS 6A6-2A9-3 EXCEPT AS NOTED
5.25
2.60
18.66
4.60
2.79
3.06
.50
1.00
2.00
2.27
1.36
1.11
1.38
1.35
SEE 2A5-2A11-3 FOR DIM'S THIS AREA
STRAIGHT TAPER SEE 2A5-2A11-3
3A4-2
F33615-76-C-3111
THE BOEING COMPANY
BULKHEAD CASTING
STATION 170
C.A.S.T
J 81205 162-00017
PCM
162-00017 A14

3

162-00018

	6	5	4	
D				
C				
B				
A				
	6	5	4	

-1	162-00001	C.A.S.T. PROGRAM	TEST ONLY
[illegible]	[illegible]	[illegible]	[illegible]
	APPLICATION		

NOTES

1. [illegible]

2. DATUM TARGET PT. DIM. GENL DWG TOL. DOES NOT APPLY.

3. NAS 77400-00P BUSHINGS ARE OPTIONAL TO BAC B28A00M000 IN EQUIV. DIA. & LENGTH.

4. STEP RESULTING FROM CASTING DRAFT.

5. 125/ ALL MACHINED SURFACES EXCEPT AS NOTED

6. BREAK ALL SHARP EDGES .03 ±.02.

7. INSTALL BUSHINGS WITH WET PRIMER (F20.04) PER BAC 5436

8. CASTING REFERENCE ONLY

9. ALL HOLES ON THIS ℄ THRU THE LANDING GEAR FITTING LUGS TO BE CONCENTRIC WITHIN .002.

10. SPOTFACE 1.75 DIA. FLAT, .05-.07 FILLET RADIUS, ONLY AS REQD TO PROVIDE FLAT SURFACE FOR BUSHING FLANGE, .12 MAX DEPTH.

11. PENETRANT INSPECT MACHINED SURFACES PER BAC 5423.

REV STATUS

SH	LTR
2	
3	
4	

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

PARTS LIST

QTY REQD -1	FIND NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	CODE IDENT NO	WT TO	FINISH	PT CD	REV LTR
4		BAC B28X20M090	BUSHING 3	[illegible]						
2		BAC B28X20M075	BUSHING 3	[illegible]						
2		BAC B28X16M095	BUSHING 3	[illegible]						
2		BAC B28X16M085	BUSHING 3	[illegible]						
1		-2	BULKHEAD	A4-2	MAKE FROM 162-00017-1 11		—	F17.04	R	
—		-1	BULKHEAD ASSY				—		R	

CONTRACT NUMBER F33615-76-C-3111

DRN F. C. Jones

THE BOEING COMPANY

BULKHEAD ASSEMBLY
STATION 170
C.A.S.T

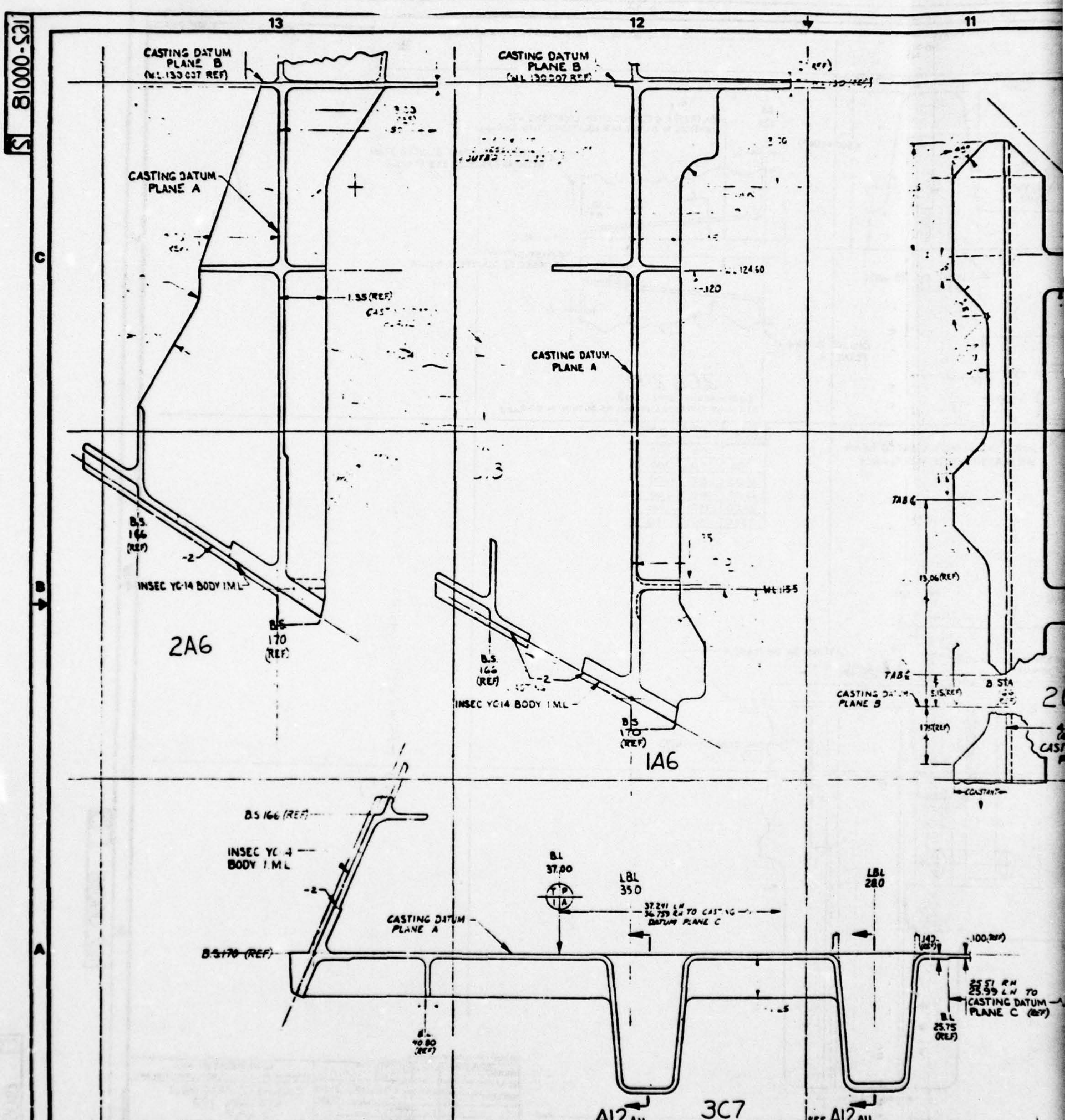
SIZE J | CODE IDENT NO 81205 | 162-00018

SH 1 OF 4

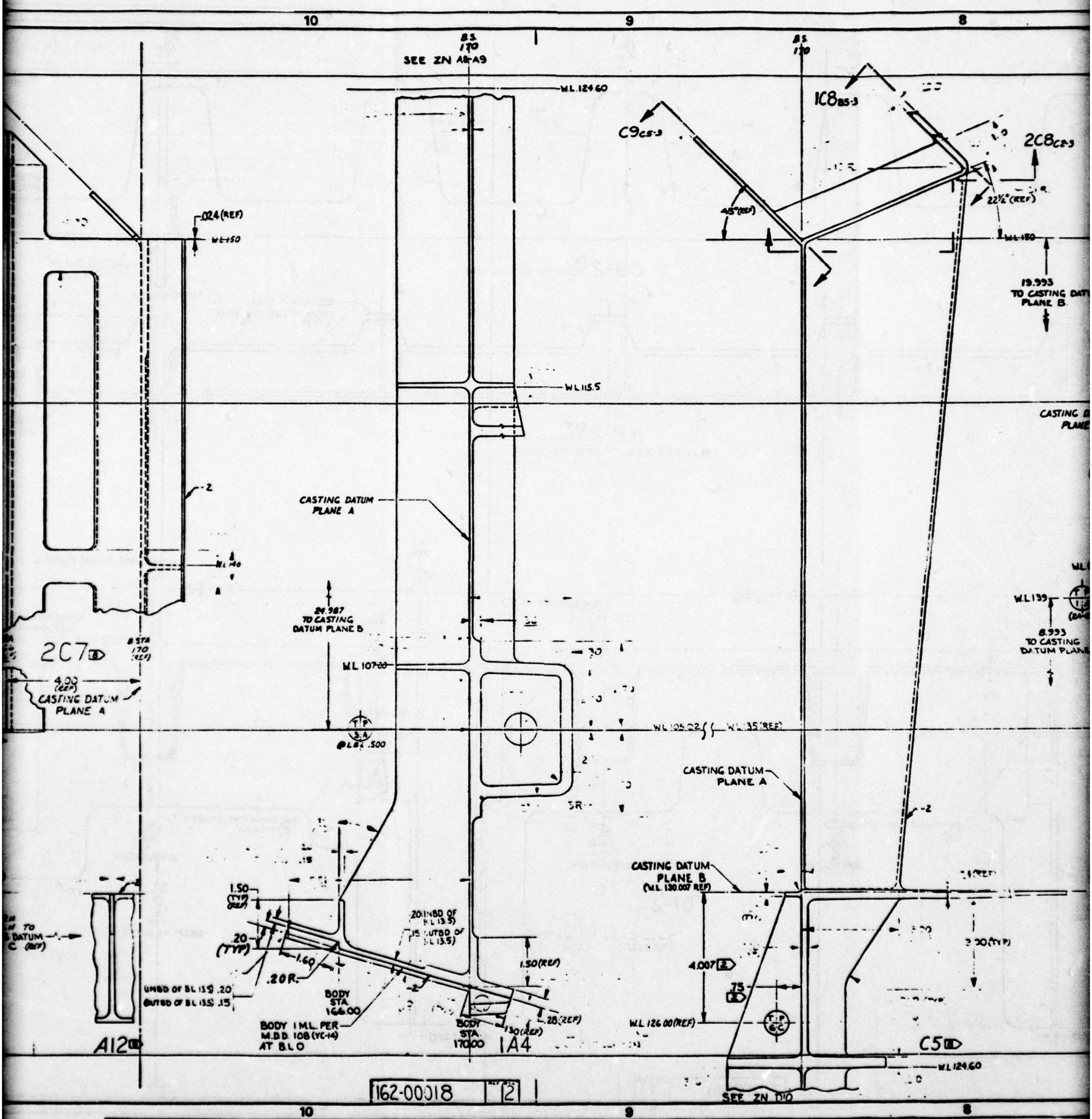
FASTENER CODES

162-00018

2

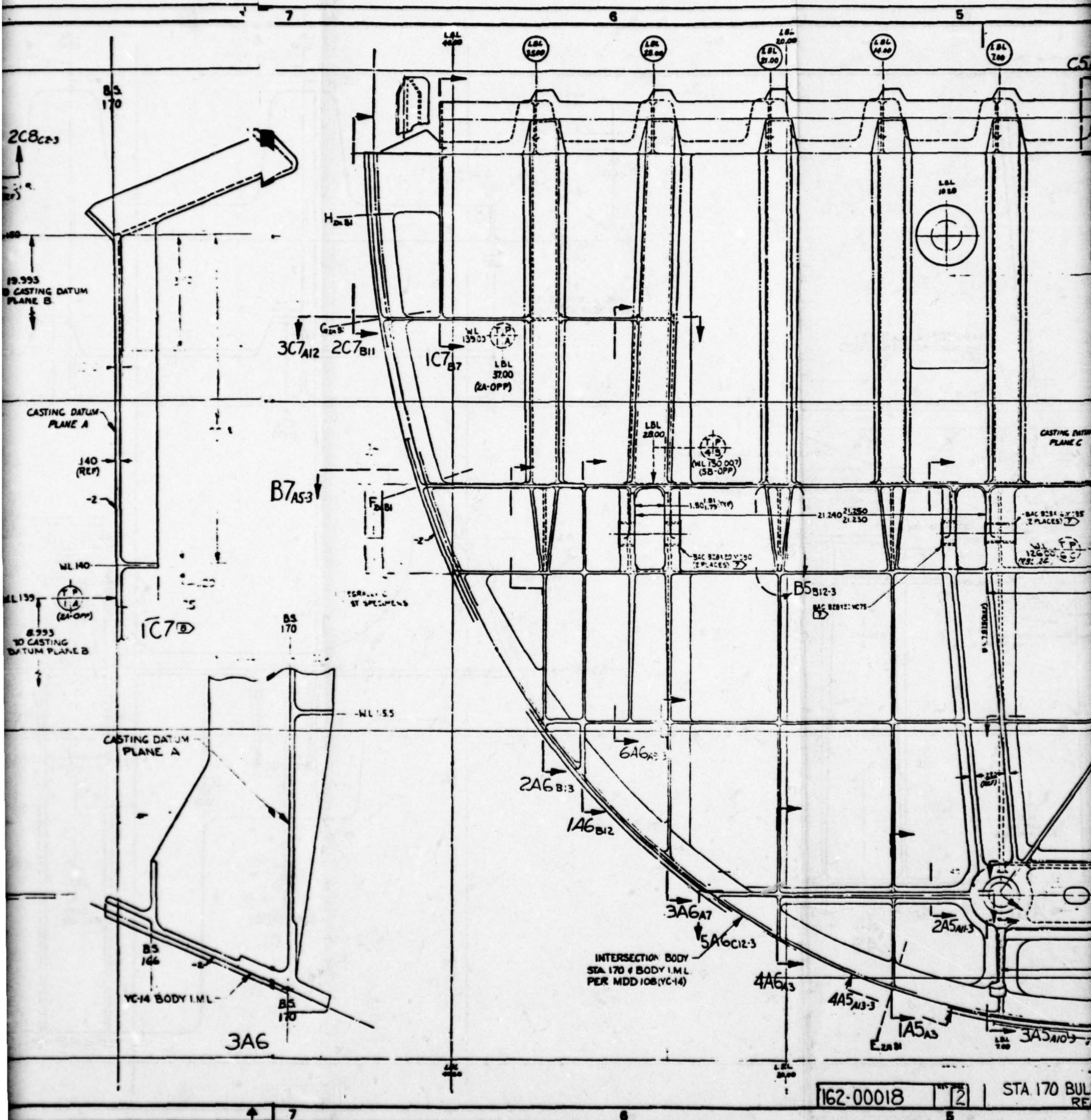


81000-S212
13
12
11
CASTING DATUM PLANE B (W.L. 130.007 REF)
CASTING DATUM PLANE A
1.35 (REF)
W.L. 124.60
.120
B.S. 166 (REF)
INSEC YC-14 BODY I.M.L.
B.S. 170 (REF)
2A6
1A6
W.L. 115.5
TAB C
13.06 (REF)
CASTING DATUM PLANE B
B STA
B.S. 166 (REF)
INSEC YC-14 BODY I.M.L.
B.L. 37.00
LBL 35.0
LBL 28.0
37.241 LH 36.759 RH TO CASTING DATUM PLANE C
CASTING DATUM PLANE A
B.S. 170 (REF)
25.51 RH 25.99 LH TO CASTING DATUM PLANE C (REF)
B.L. 25.75 (REF)
B.L. 40.80 (REF)
A12 A11
3C7
SEE A12 A11
C
B
A



10
9
8
B.S. 170
SEE ZN A8-A9
W.L. 124.60
1C8 B5-3
C9 C5-3
2C8 C2-3
45°(REF)
22½°(REF)
.024(REF)
W.L. 150
19.993 TO CASTING DATUM PLANE B
W.L. 115.5
CASTING DATUM PLANE
-2
CASTING DATUM PLANE A
W.L. 140
24.987 TO CASTING DATUM PLANE B
W.L. 139
8.993 TO CASTING DATUM PLANE
2C7
B STA 170 (REF)
4.00 (REF)
CASTING DATUM PLANE A
W.L. 107.00
W.L. 105.22
W.L. 135 (REF)
@ B.L. .500
CASTING DATUM PLANE A
CASTING DATUM PLANE B (W.L. 130.007 REF)
1.50 (TYP) (REF)
.20 (TYP)
1.60
.20R.
.20 (INBD OF B.L. 13.5)
.15 (OUTBD OF B.L. 13.5)
1.50(REF)
(INBD OF B.L. 13.5) .20
(OUTBD OF B.L. 13.5) .15
BODY STA 166.00
BODY I.M.L. PER M.B.D. 108 (YC-14) AT B.L.O
BODY STA 170.00
.28(REF)
.130(REF)
4.007
.75
3.00(TYP)
W.L. 126.00 (REF)
W.L. 124.60
A12
1A4
C5
SEE ZN D10
162-00018
2

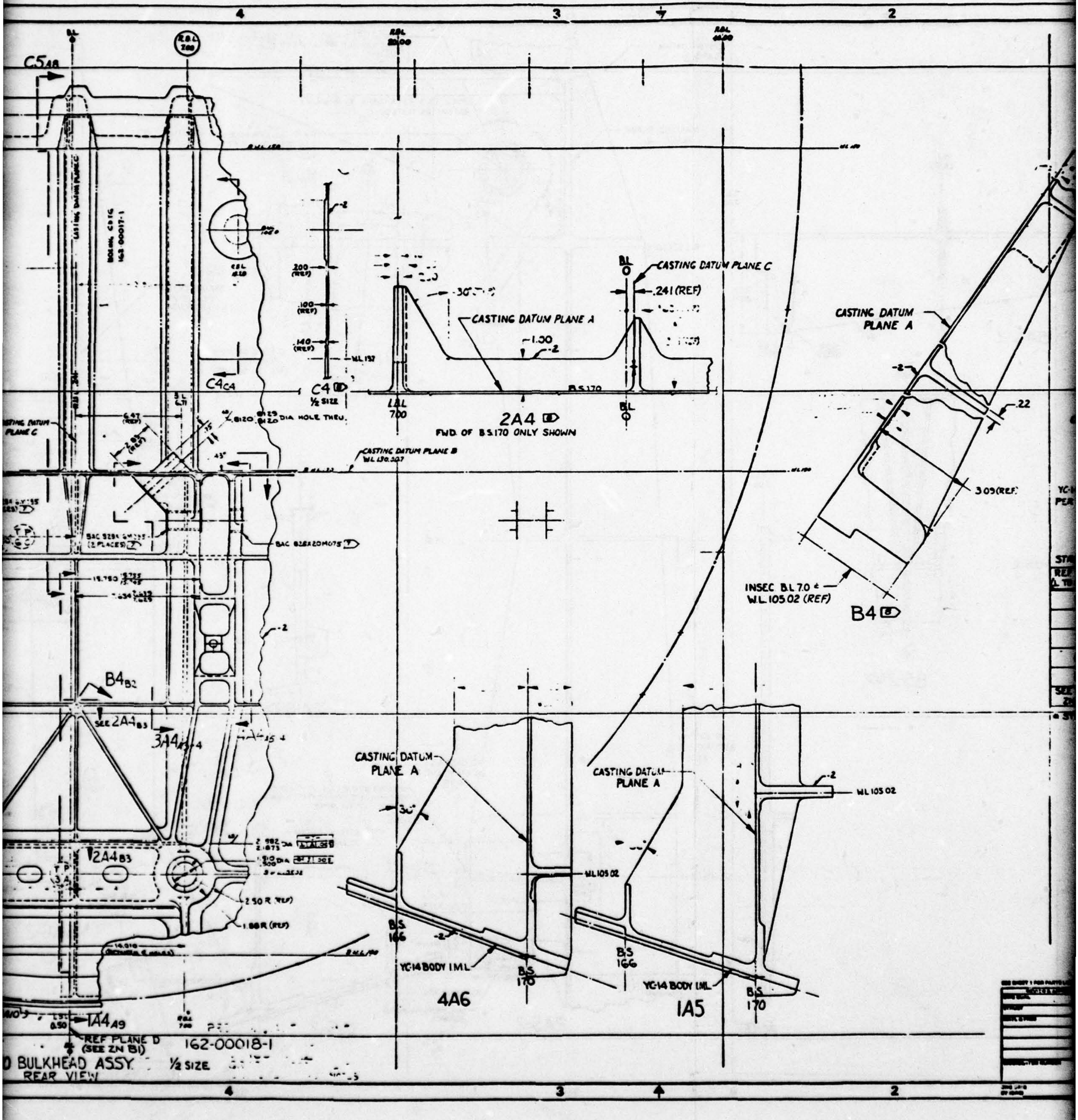
2



162-00018 | 2 | STA 170 BULK... REAR...

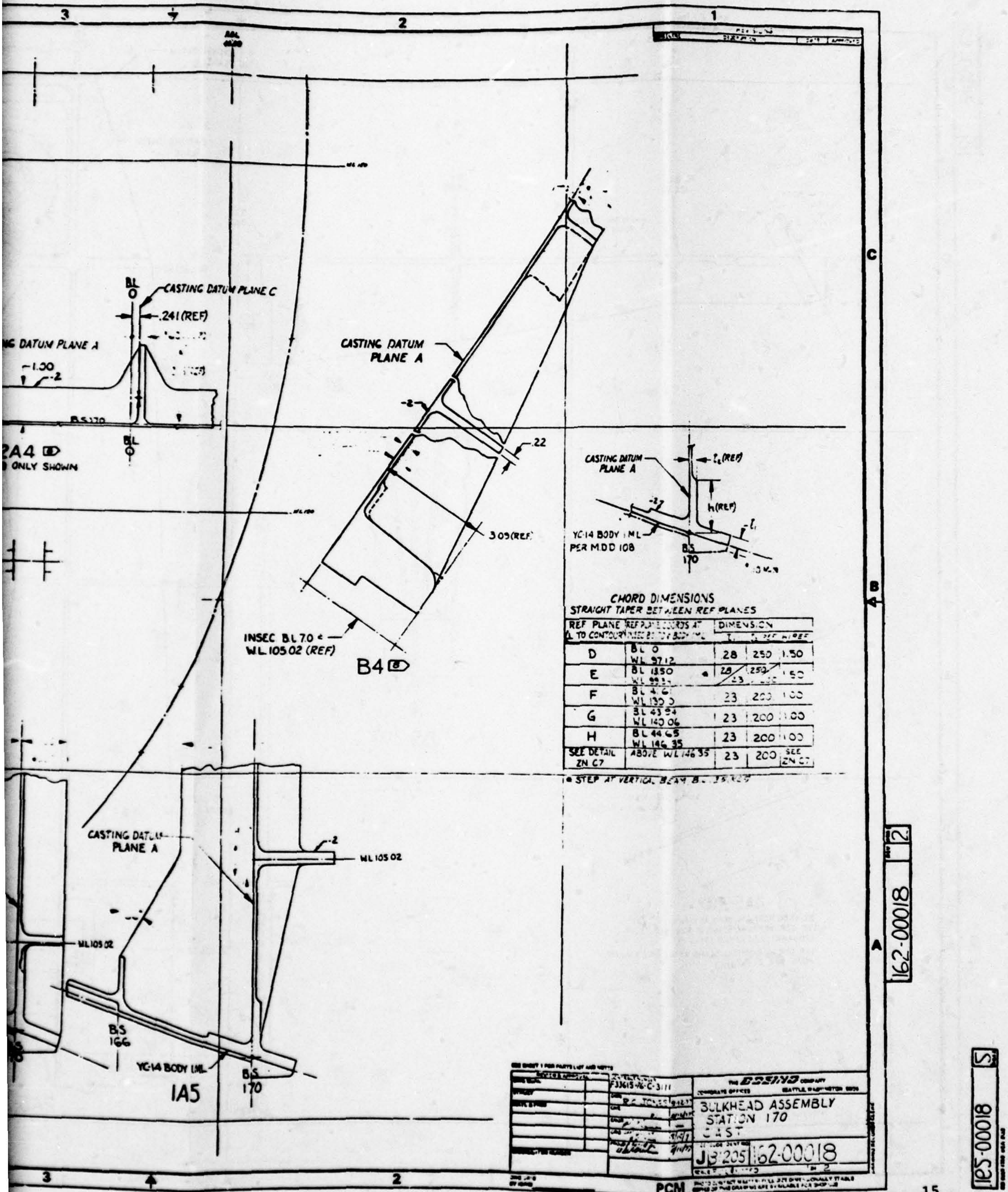
7 6 5

3



C5 A8
CASTING DATUM PLANE C
CASTING DATUM PLANE A
.241 (REF)
-1.00
B.S.170
C4 C4
C4
1/2 SIZE
LBL 7.00
2A4
FWD. OF B.S.170 ONLY SHOWN
.8120 DIA HOLE THRU.
CASTING DATUM PLANE B
W.L.130.307
BAC B28X20M075
BAC 5284 (2 PLACES)
CASTING DATUM PLANE A
-2
.22
3.05 (REF)
INSEC B.L.7.0 & W.L.105.02 (REF)
B4
B4 B2
SEE 2A4 B3
3A4 B3-4
2A4 B3
2.50 R (REF)
1.88R (REF)
1A4 A9
REF PLANE D (SEE ZN B1)
162-00018-1
D BULKHEAD ASSY. 1/2 SIZE
REAR VIEW
CASTING DATUM PLANE A
30°
W.L.105.02
B.S. 166
B.S. 170
YC-14 BODY I.M.L.
4A6
CASTING DATUM PLANE A
W.L.105.02
B.S. 166
YC-14 BODY I.M.L.
B.S. 170
1A5
4
3
2

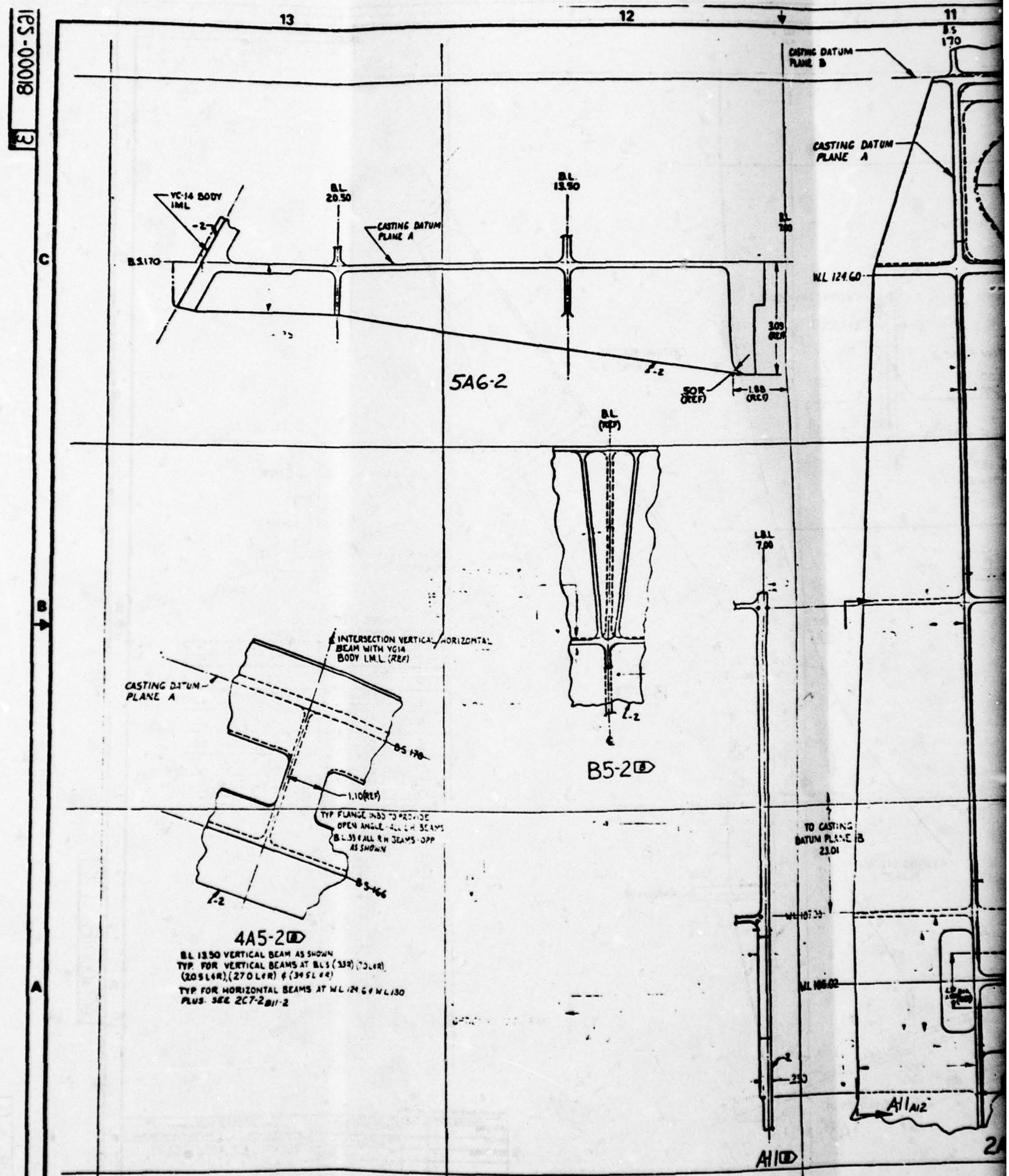
4



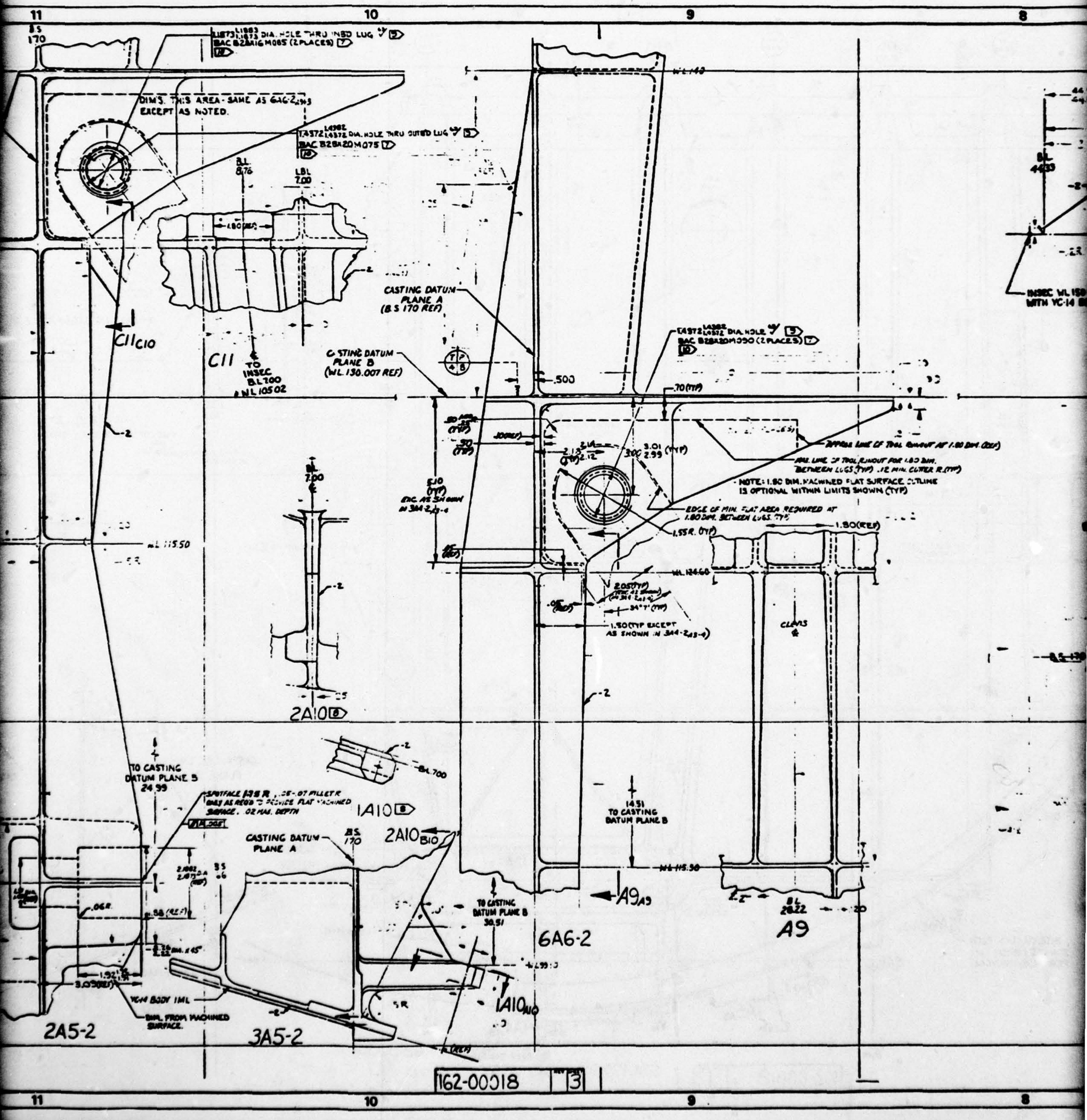
CHORD DIMENSIONS
STRAIGHT TAPER BETWEEN REF PLANES

REF PLANE ℄ TO CONTOUR	REF PLANE COORDS AT INSEC BL ℄ BODY IML	DIMENSION t_1	t_2 REF	h REF
D	BL 0 WL 97.12	.28	.250	1.50
E	BL 13.50 WL 99.3[illegible] ●	.28 / .23	.250 / .200	1.50
F	BL 4[illegible] WL 130.[illegible]	.23	.200	1.00
G	BL 43.94 WL 140.06	.23	.200	1.00
H	BL 44.65 WL 146.35	.23	.200	1.00
SEE DETAIL ZN C7	ABOVE WL 146.35	.23	.200	SEE ZN C7

● STEP AT VERTICAL BEAM BL [illegible]

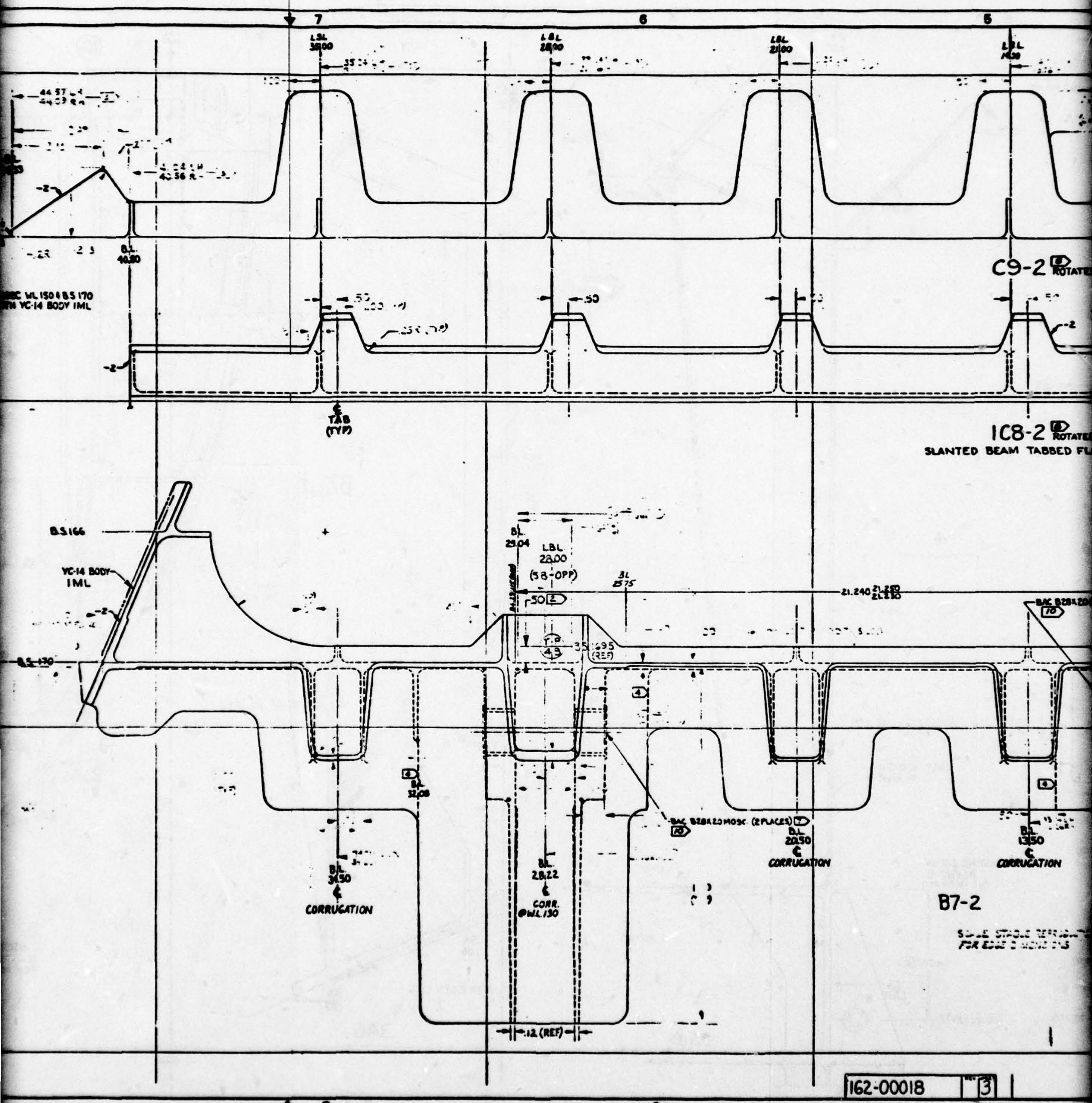


1C52-0008
E
13
12
11
C
B
A
B.S. 170
CASTING DATUM PLANE B
CASTING DATUM PLANE A
W.L. 124.60
YC-14 BODY IML
B.L. 20.50
B.L. 13.50
B.L. 7.00
B.S. 170
3.09 (REF)
.50R (REF)
1.88 (REF)
5A6-2
B.L. (REF)
B5-2
℄ INTERSECTION VERTICAL/HORIZONTAL BEAM WITH YC14 BODY I.M.L. (REF)
CASTING DATUM PLANE A
B.S. 170
1.10 (REF)
TYP FLANGE INBD TO PROVIDE OPEN ANGLE - ALL L.H. BEAMS
B.L. 13.5 ℄ ALL R.H. BEAMS - OPP AS SHOWN
B.S. 166
4A5-2
B.L. 13.50 VERTICAL BEAM AS SHOWN
TYP. FOR VERTICAL BEAMS AT B.L.S (13.5), (7.0 L ≠ R), (20.5 L ≠ R), (27.0 L ≠ R) ≠ (34.5 L ≠ R)
TYP. FOR HORIZONTAL BEAMS AT W.L. 124.6 ≠ W.L. 130
PLUS: SEE 2C7-2 B11-2
L.B.L. 7.00
TO CASTING DATUM PLANE B 23.01
W.L. 107.35
W.L. 106.02
.250
A11 A12
A11



DIM'S. THIS AREA - SAME AS 6A6-2
EXCEPT AS NOTED.
CASTING DATUM PLANE A (B.S 170 REF)
CASTING DATUM PLANE B (W.L. 130.007 REF)
C11 C10
C11
2A10
1A10
2A10 B10
CASTING DATUM PLANE A
TO CASTING DATUM PLANE B
6A6-2
A9 A9
A9
1A10 A10
2A5-2
3A5-2
NOTE: 1.80 DIM. MACHINED FLAT SURFACE OUTLINE IS OPTIONAL WITHIN LIMITS SHOWN (TYP)
EDGE OF MIN. FLAT AREA REQUIRED AT 1.80 DIM. BETWEEN LUGS (TYP)
APPROX LINE OF TOOL RUNOUT AT 1.80 DIM. (REF)
1.50 (TYP EXCEPT AS SHOWN IN 3A4-2)
1.80 (REF)
TO CASTING DATUM PLANE B
YC-14 BODY IML
DIM. FROM MACHINED SURFACE.

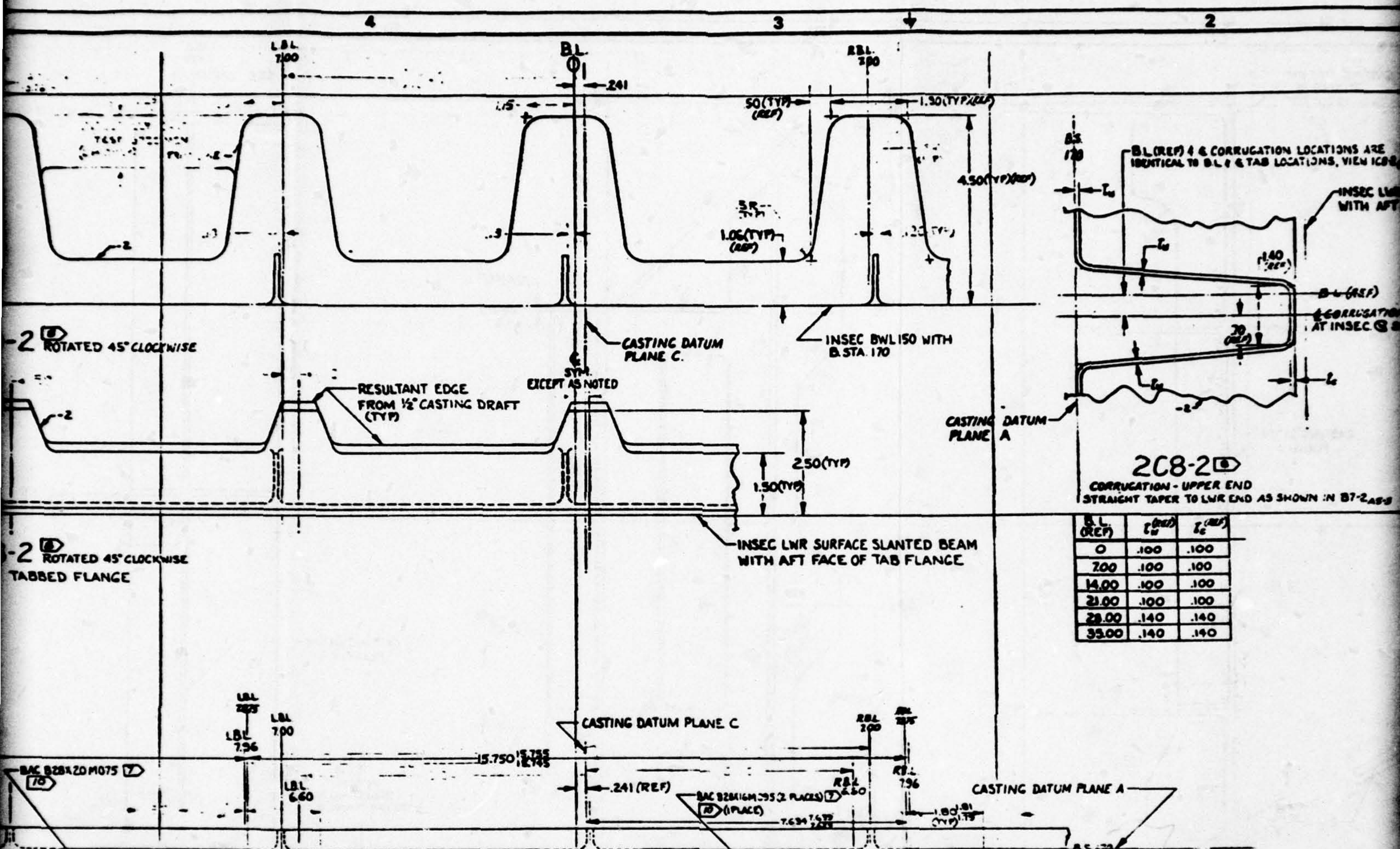
162-00018 3



162-00018 3

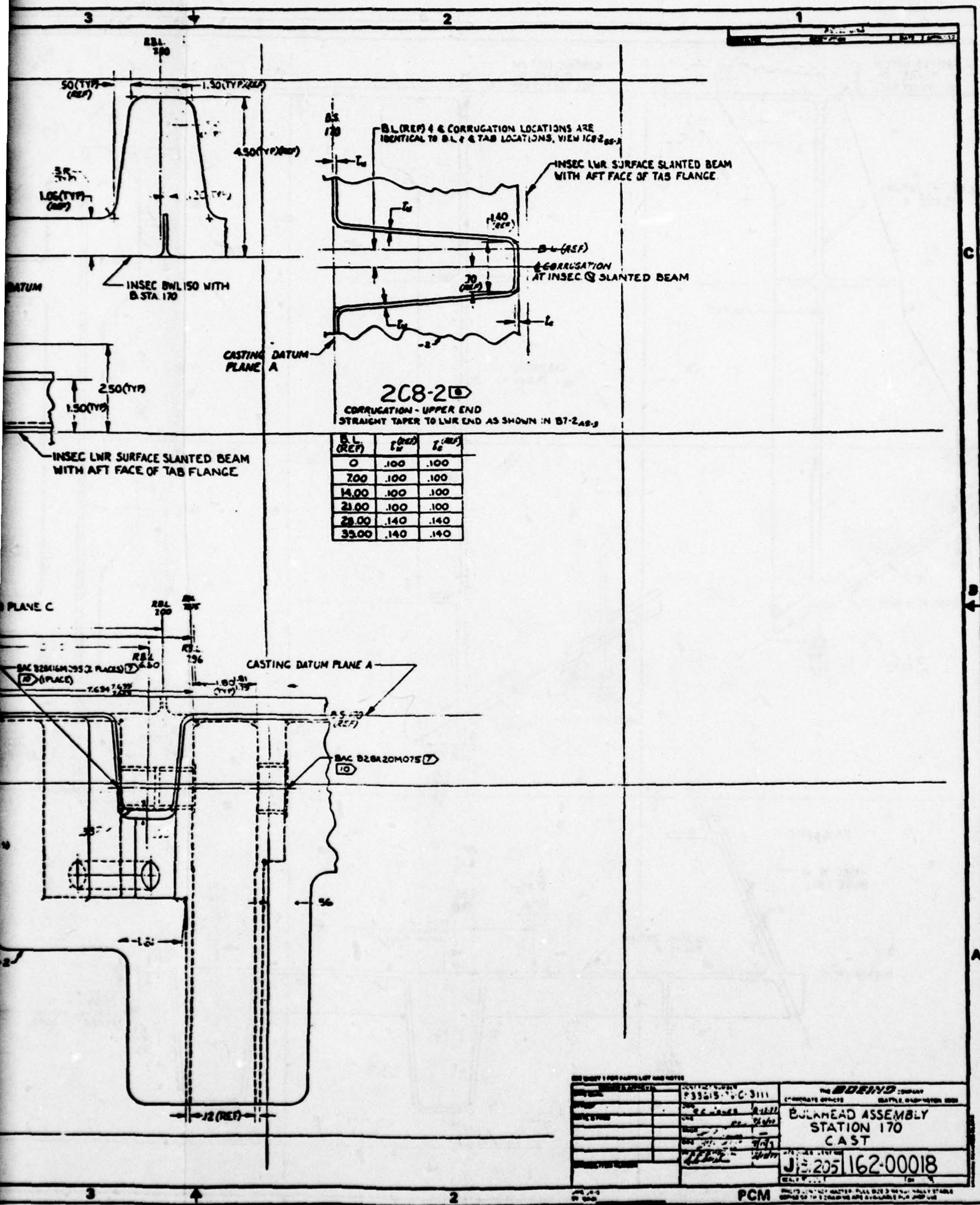
7 6 5

3



B.L. (REF)	t_U (REF)	t_L (REF)
0	.100	.100
7.00	.100	.100
14.00	.100	.100
21.00	.100	.100
28.00	.140	.140
35.00	.140	.140

4



2C8-2

CORRUGATION - UPPER END
STRAIGHT TAPER TO LWR END AS SHOWN IN B7-2

B.L. (REF)	t_w (REF)	t_c (REF)
0	.100	.100
7.00	.100	.100
14.00	.100	.100
21.00	.100	.100
28.00	.140	.140
35.00	.140	.140

4 162-00018

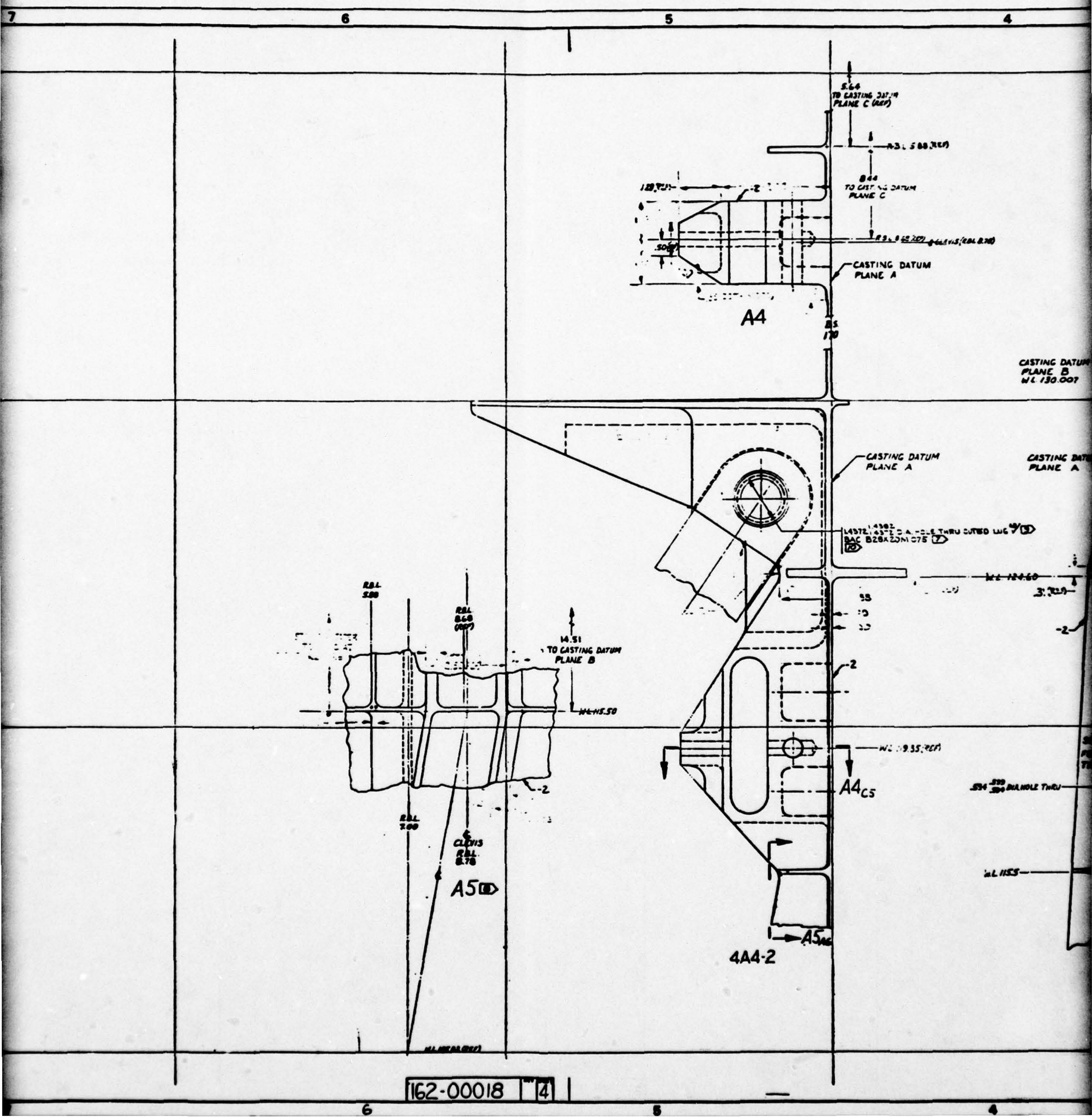
9 8 7

C

B

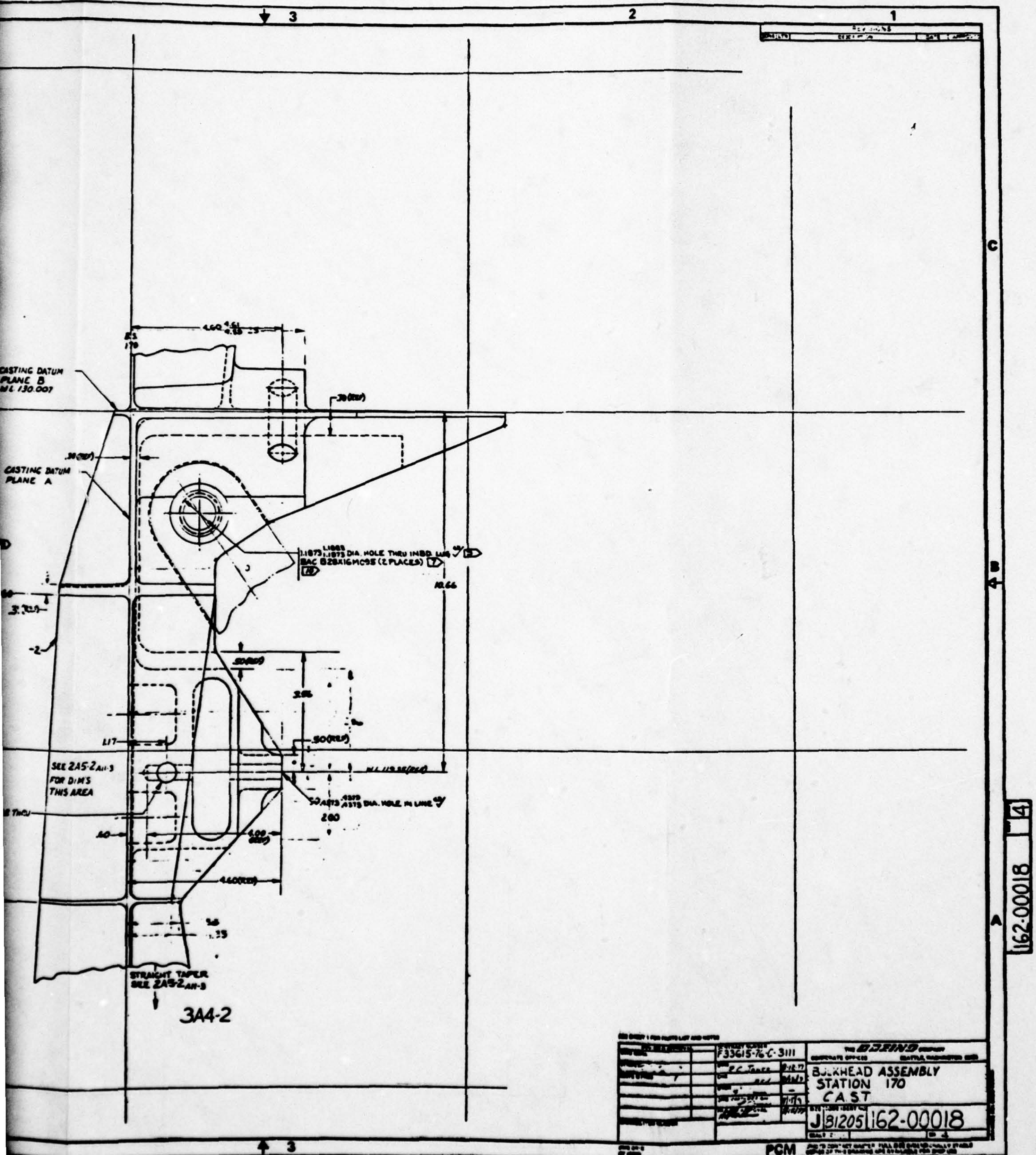
A

9 8 7



5.64
TO CASTING DATUM
PLANE C (REF)
TO CASTING DATUM
PLANE C
CASTING DATUM
PLANE A
A4
CASTING DATUM
PLANE B
W.L. 130.007
CASTING DATUM
PLANE A
CASTING DATUM
PLANE A
BAC B28AZ3M C75
R.B.L.
5.88
R.B.L.
8.68
(REF)
14.51
TO CASTING DATUM
PLANE B
-2
R.B.L.
7.00
CLEVIS
R.B.L.
8.78
A5
A4
A5
4A4-2

162-00018 4



CASTING DATUM PLANE B WL 130.007
CASTING DATUM PLANE A
1.1873 DIA. HOLE THRU INBD LUG
BAC B28X16MC95 (2 PLACES)
10.66
SEE 2A5-2 FOR DIM'S THIS AREA
STRAIGHT TAPER SEE 2A5-2
3A4-2
F33615-76-C-3111
BULKHEAD ASSEMBLY
STATION 170
CAST
J 81205 162-00018
PCM
162-00018

17

185-00018

5. BASELINE COMPONENT DATA

a. Initial Baseline Component Data

The initial baseline cost data were derived during Phase I, Preliminary Design. The first unit YC-14 bulkhead total cost was estimated to be $122,000 and the projected unit cost of the bulkhead, based on a 300-airplane production run, was $10,900. These costs were derived primarily from actual records and are for the built-up baseline component bulkhead prior to release of the updated baseline data.

The initial baseline component weight was 184.6 lb. This weight was the actual weight of the YC-14 baseline component bulkhead and did not reflect a reduction for non-optimum prototype structures.

b. Updated Baseline Component Data

A baseline component revision was released September 30, 1977. The revised baseline component includes the original YC-14 bulkhead components plus that portion of the slanted beam assembly at WL 150 between LBL 41.0 and RBL 41.0. The updated cost summary is shown in figure 2, giving both the first unit cost and the projected unit cost based on a 300-airplane production run. The $12,894 figure replaces the $10,900 previously used for a cost comparison of the cast concept versus the baseline component.

The revised baseline component weight is 187.6 lb. This weight is for the YC-14 component components plus the WL 150 slanted beam between LBL 41.0 and RBL 41.0, and also includes the deletion of non-optimum weight items that would not be required on a production (YC-14) bulkhead.

	No. 1 A/P cost	300 A/P cost
Raw material	$ 1,228	$ 384,000
Labor:		
Detail tools	45,450	302,577
Assembly tools	55,325	366,345
Detail fabrication	45,250	1,701,120
Sub-assembly	9,750	743,505
Section installation	– –	247,680
Total	$157,003	$3,745,227
Cost per unit	$157,003	$ 12,484

Figure 2 . Conventionally Fabricated Station 170 Bulkhead Costs Updated Baseline Component

SECTION III

ANALYSIS

1. STATIC STRENGTH ANALYSIS

The YC-14 design loads were used to structurally size the cast bulkhead and transition structure. A finite element computer model was used to calculate the internal loads. The exploded computer model geometry of the cast bulkhead and transition structure (fig. 3) is shown on figures 4 and 5. Detailed sections of the computer model showing nodes, rods, beams, and plates can be seen in figures 6 through 14. Loads were applied at specific nodes to simulate landing gear loads and loads due to a jammed landing gear door actuator. All nodes in the computer model are fixed at station 230.

Detailed stress analysis of major critical components includes:

o Lug analysis of BL 28	(Figure 15)
o Critical webs	(Figures 16 through 20)
o Stiffener at BL 28	(Figures 21 through 27)
o Horizontal beam at WL 150	(Figures 28 through 30)
o Bulkhead perimeter chord	(Figures 31 through 33)
o Backup structure for landing gear door actuator	(Figures 34 and 35)
o Lug backup structure at BL 8.7	(Figure 36)

a. Summary of Margins of Safety

The following summarizes the margins of safety of the critical components. The least margins of safety were found for the lug at BL 28 and for the perimeter beam at WL 150. The lug exhibits a positive 9% margin of safety for the maximum tensile force and the perimeter beam also shows a 9% positive margin of safety for combined bending and axial loads.

Critical Component	Fig. No.	M.S.
Critical lug at BL 28		
Shear-Bearing	15	+0.13
Tension	15	+0.09
Critical webs		
t = 0.1	17	+0.67
t = 0.14	18	+0.29
Critical stiffener at BL 28		
WL 150	24	+0.82
WL 140	24	+0.72
WL 130	25	+0.32
	26	+0.33
	26	+0.64
WL 124.7	27	+0.75
		High
Horizontal beam at WL 150		
Upper flange	30	High
Web	30	High
Perimeter beam		
Inboard of BL 13.5	30	+0.09
Outboard of BL 13.5	30	+0.22
Torque box at WL 105		
Tension	35	+0.50
Compression	35	+0.10
Lug backup structure at BL 8.7	36	+0.24

b. Finite Element Analysis of Cast Bulkhead and Transition Structure

Figures 4 through 14 show the details of the finite element model used to determine the internal loads. The model consists of 276 nodes and 895 elements. It represents the structure indicated on figure 3. Figure 4 represents an exploded view of the model, while the detail nodal diagrams are shown on figures 6 through 14.

c. Critical Components Stress Analysis

Figures 15 through 36 contain the strength analysis of the critical components of the bulkhead. The margins of safety are summarized in Section III.1.a.

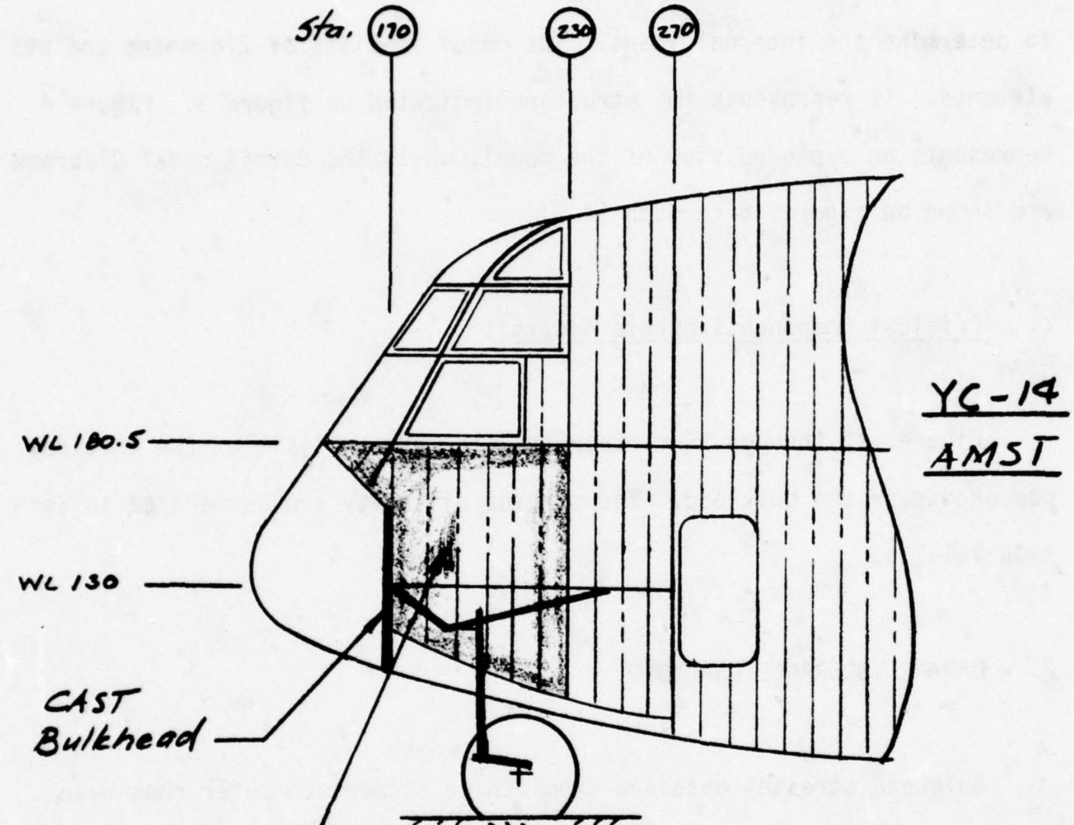
2. DAMAGE TOLERANCE ANALYSIS

Bulkhead stresses obtained from finite element computer runs were reviewed to determine which points would be considered damage tolerance critical. The details selected for this analysis are:

- o Outer load attachment point A (fig. 37)
- o Shear web located between LBL 28-LBL 32 and WL 124.7-WL 130 (fig. 37)

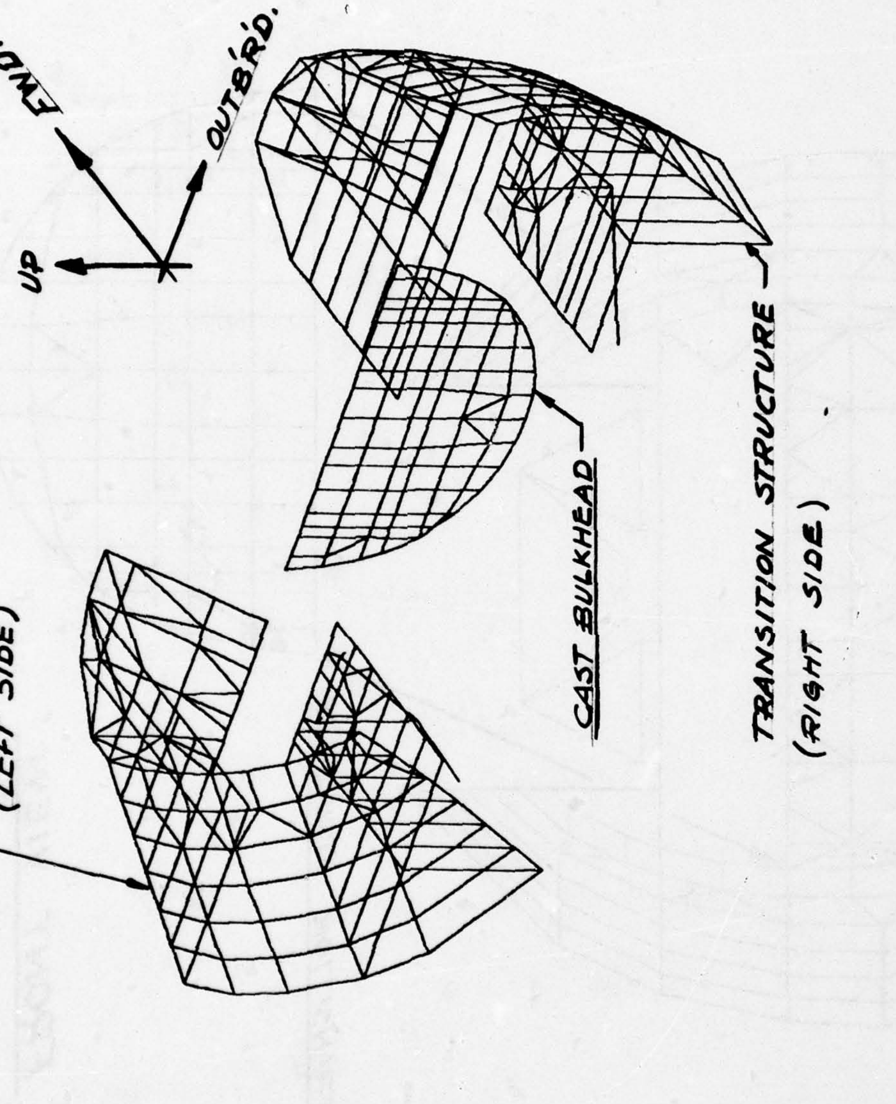
Damage tolerance analyses were performed on the respective details for the following flaw types:

- o Corner flaw at a clevis hole
- o Surface flaw in a shear web



Finite Element Computer Model of CAST Bulkhead and Transition Structure.

ENGR.	C. Ramon	11-28-77	REVISED	DATE	CAST Bulkhead and Transition Structure	CAST
CHECK	BOLLINGER	11-29-77				Fig. 3
APR						
APR					BOEING	24



EXPLODED GEOMETRY

CAST BULKHEAD & TRANSITION STRUCTURE

ENGR.	J. Romero	11-18-77	REVISED	DATE	CAST- FINITE ELEMENT COMPUTER MODEL	CAST
CHECK	BOLLINGER	11-29-77				Fig. 4
APR						
APR					BOEING	25

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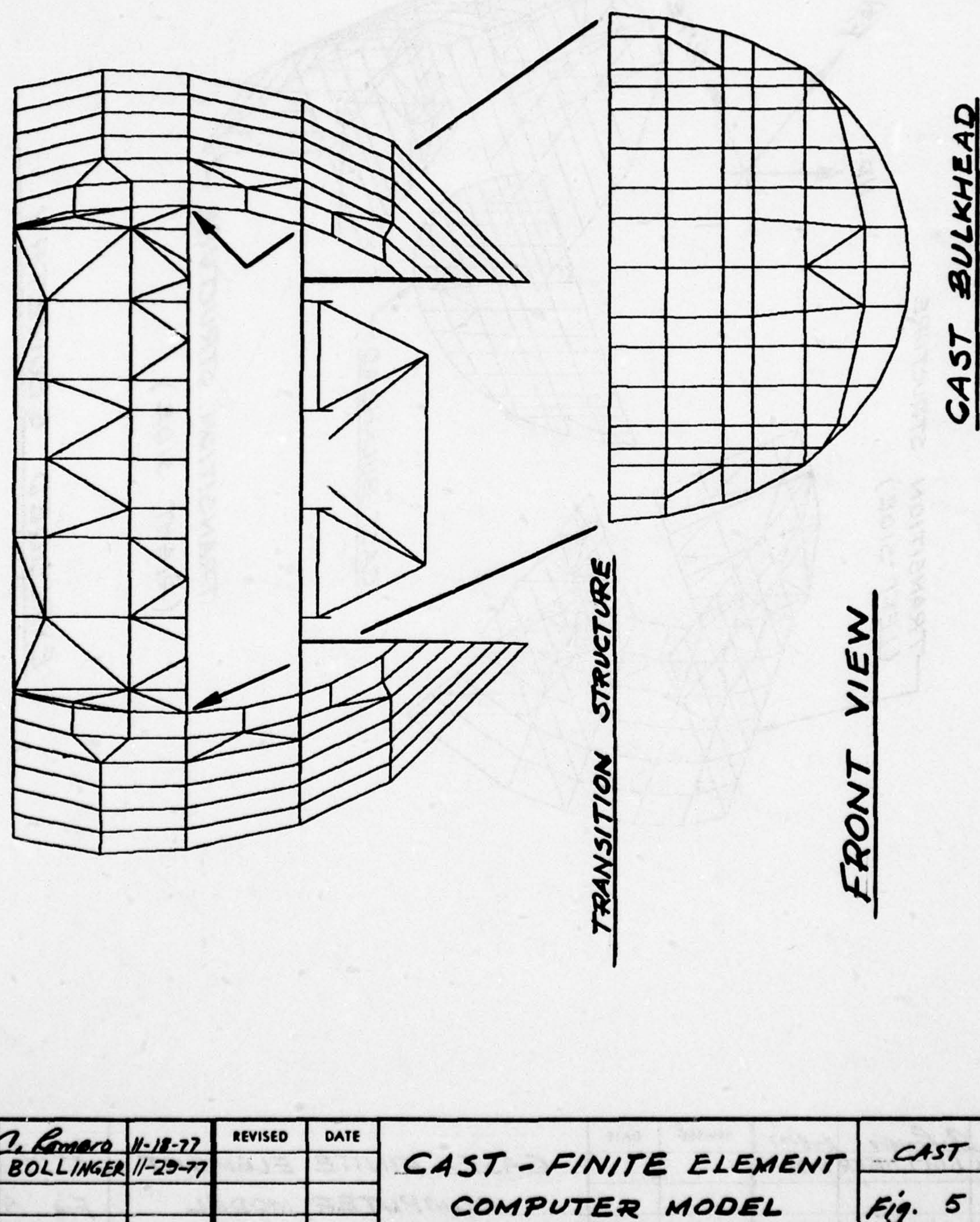
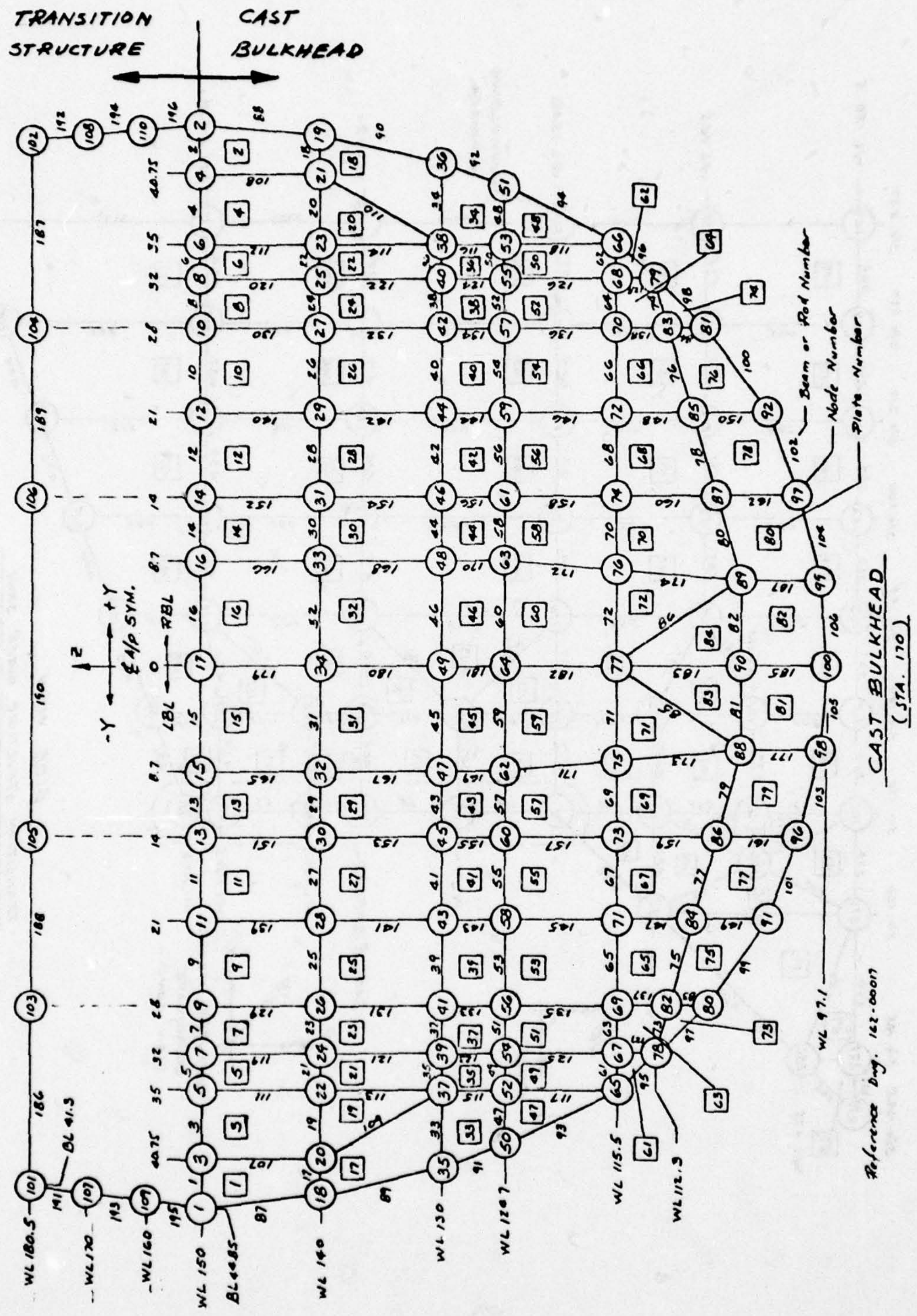
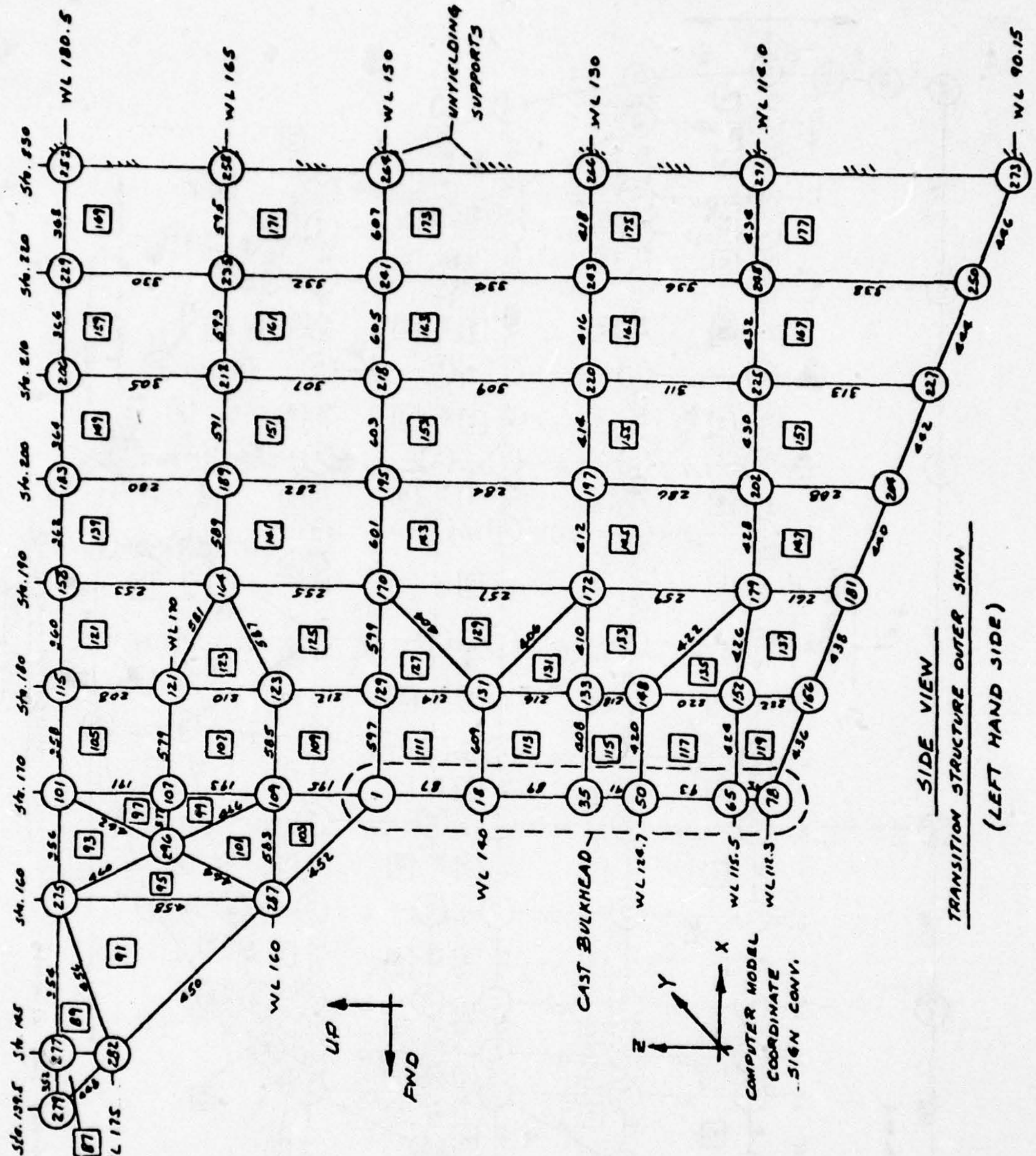


			REVISED	DATE		
ENGR.	C. Romero	11-18-77			CAST - FINITE ELEMENT	CAST
CHECK	BOLLINGER	11-29-77			COMPUTER MODEL	Fig. 5
APR					**BOEING**	26
APR						



ENGR.	C. Romero	11-10-77	REVISED	DATE	CAST- FINITE ELEMENT	CAST
CHECK	BOLLINGER	11-29-77				
APR					COMPUTER MODEL	Fig. 6
APR						
					BOEING	27



ENGR.	C. Romero	11-10-77	REVISED	DATE	CAST- FINITE ELEMENT COMPUTER MODEL	CAST
CHECK	BOLLINGER	11-29-77				Fig. 7
APR					BOEING	28
APR						

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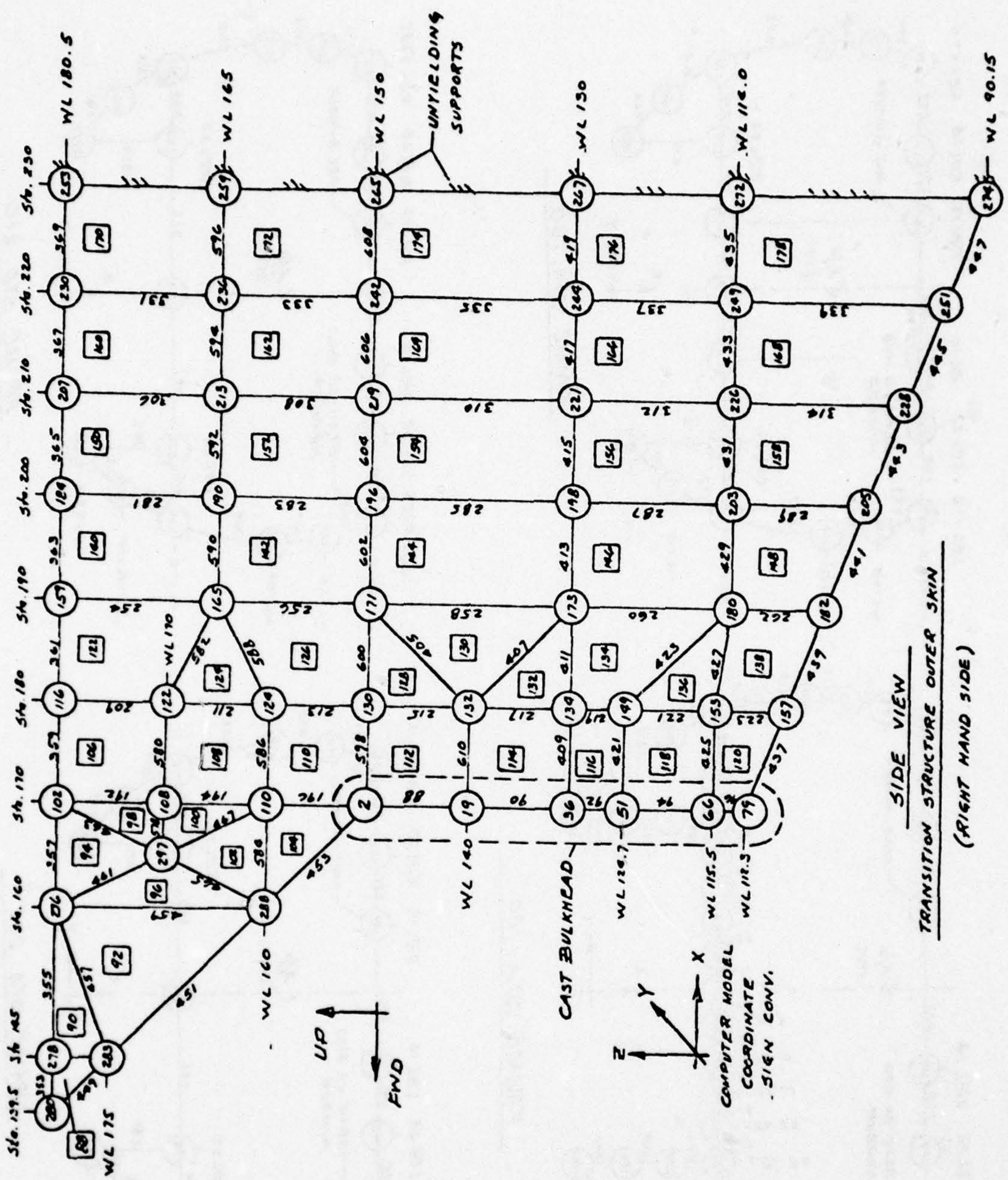
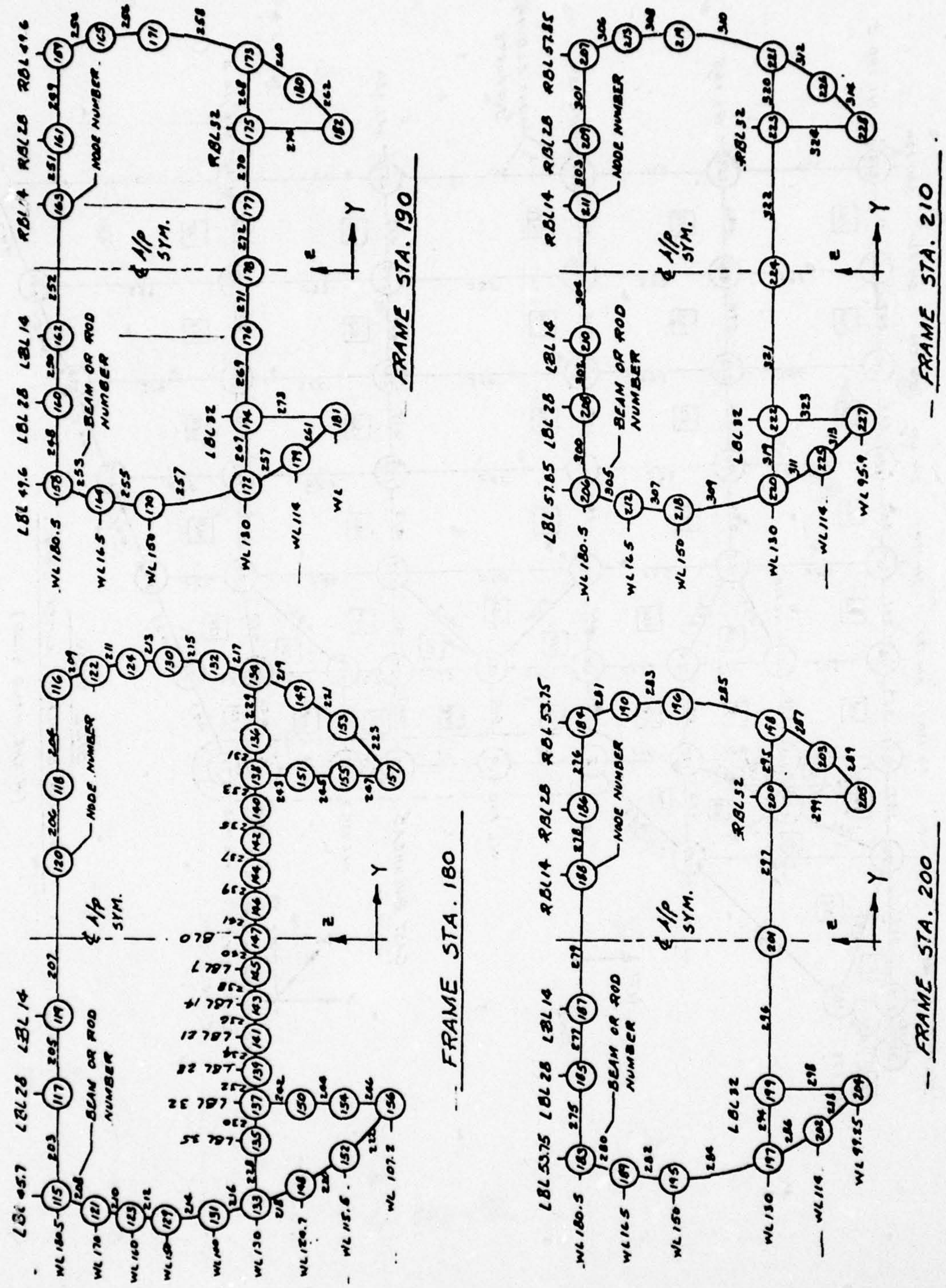


ENGR.	C. Romero	11-10-77	REVISED	DATE	CAST - FINITE ELEMENT COMPUTER MODEL	CAST
CHECK	BOLLINGER	11-29-77				Fig. 8
APR					BOEING	29
APR						

D1 4100 5320 REV.8/71 J15-047



ENGR.	C. Ramos	11-10-77	REVISED	DATE	CAST- FINITE ELEMENT COMPUTER MODEL	CAST
CHECK	BOLLINGER	11-29-77				Fig. 9
APR					**BOEING**	30
APR						

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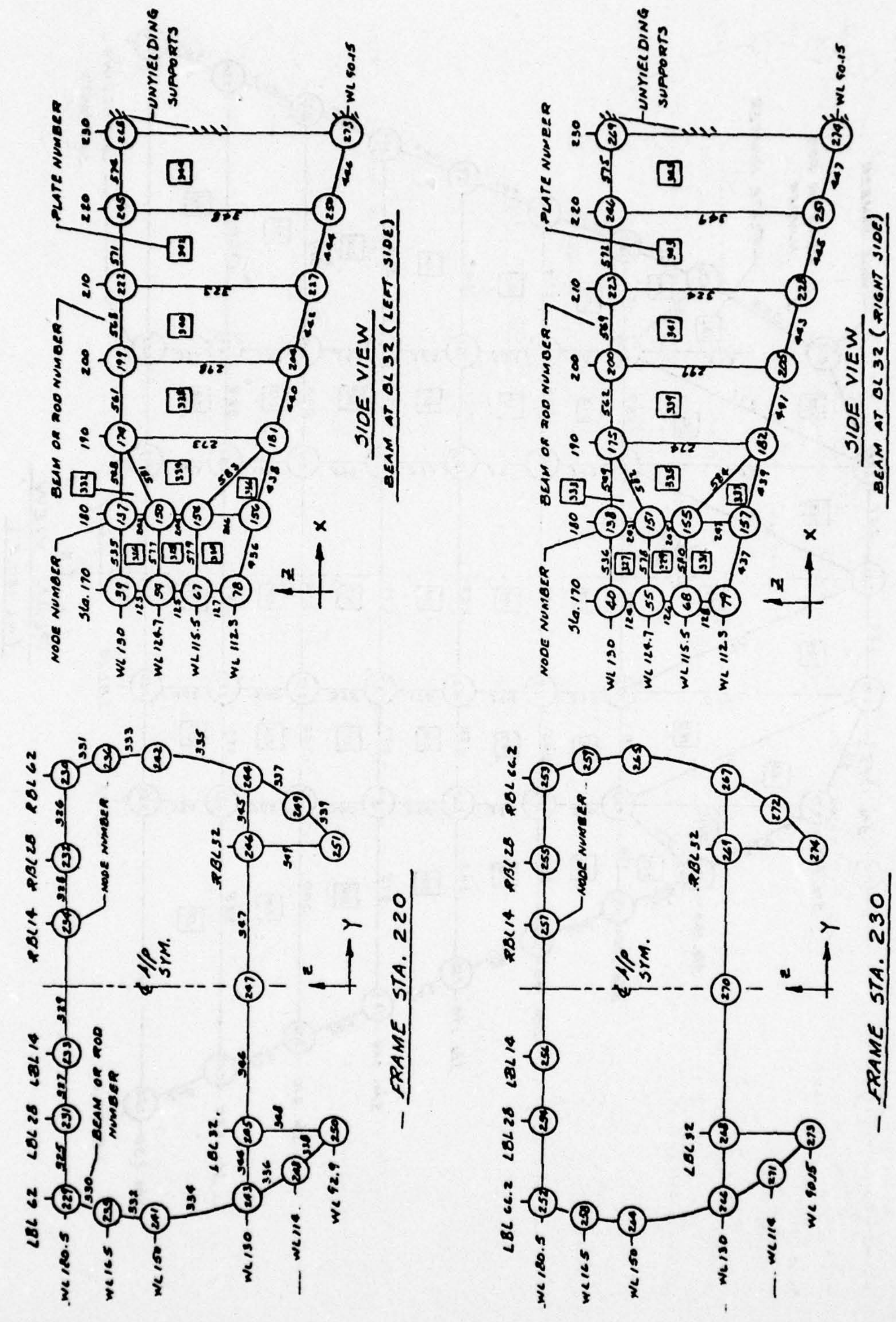
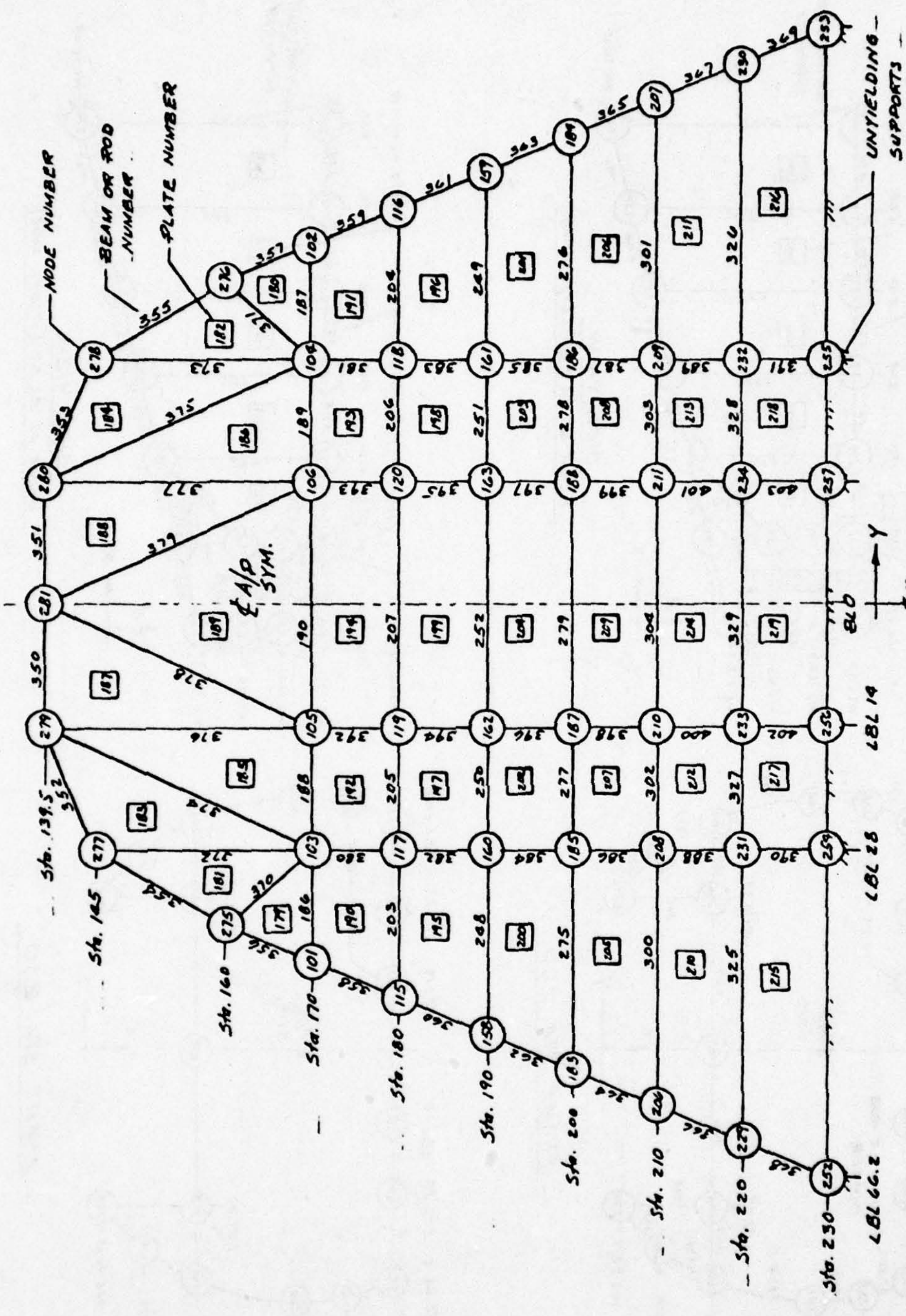
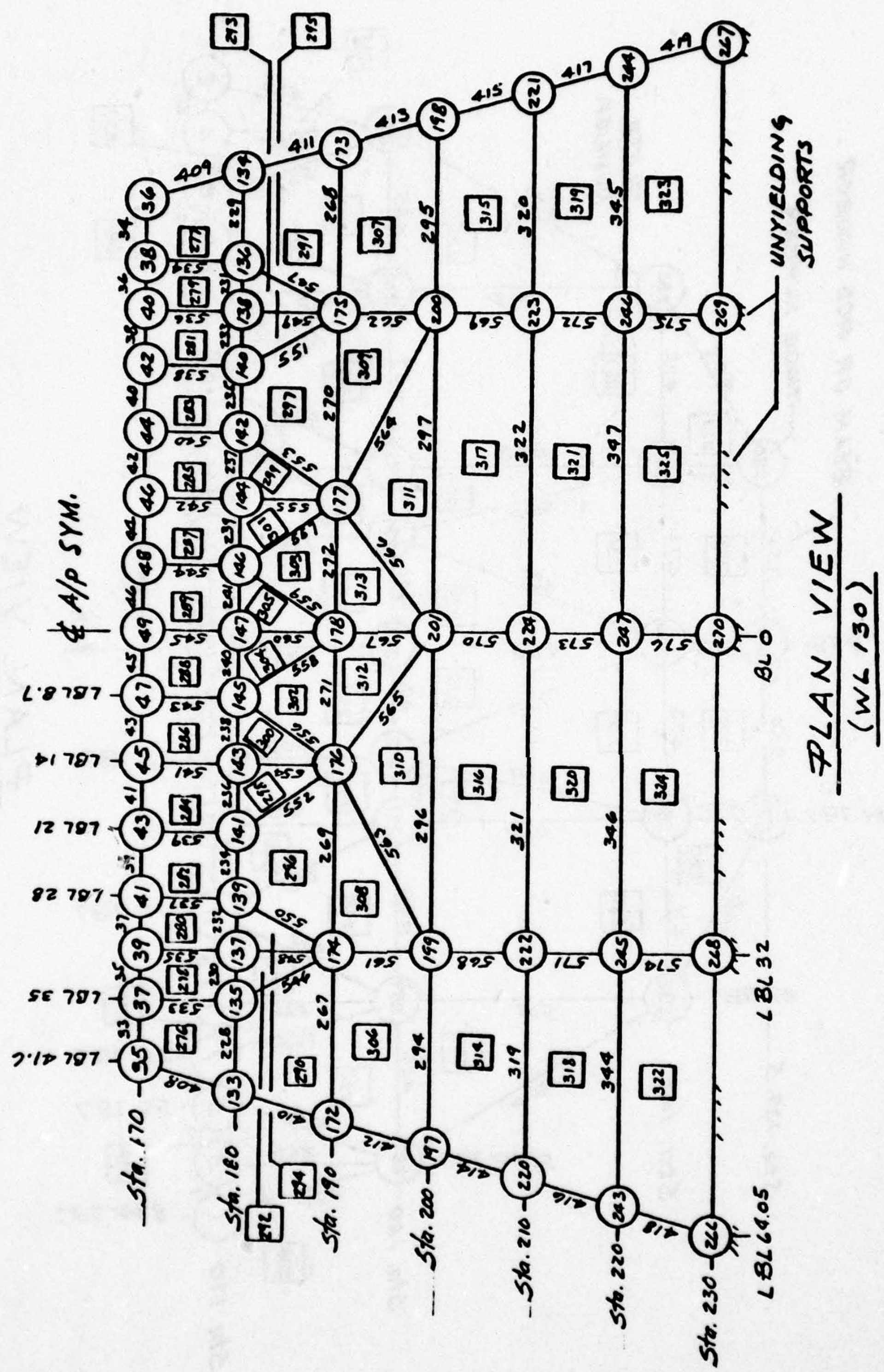


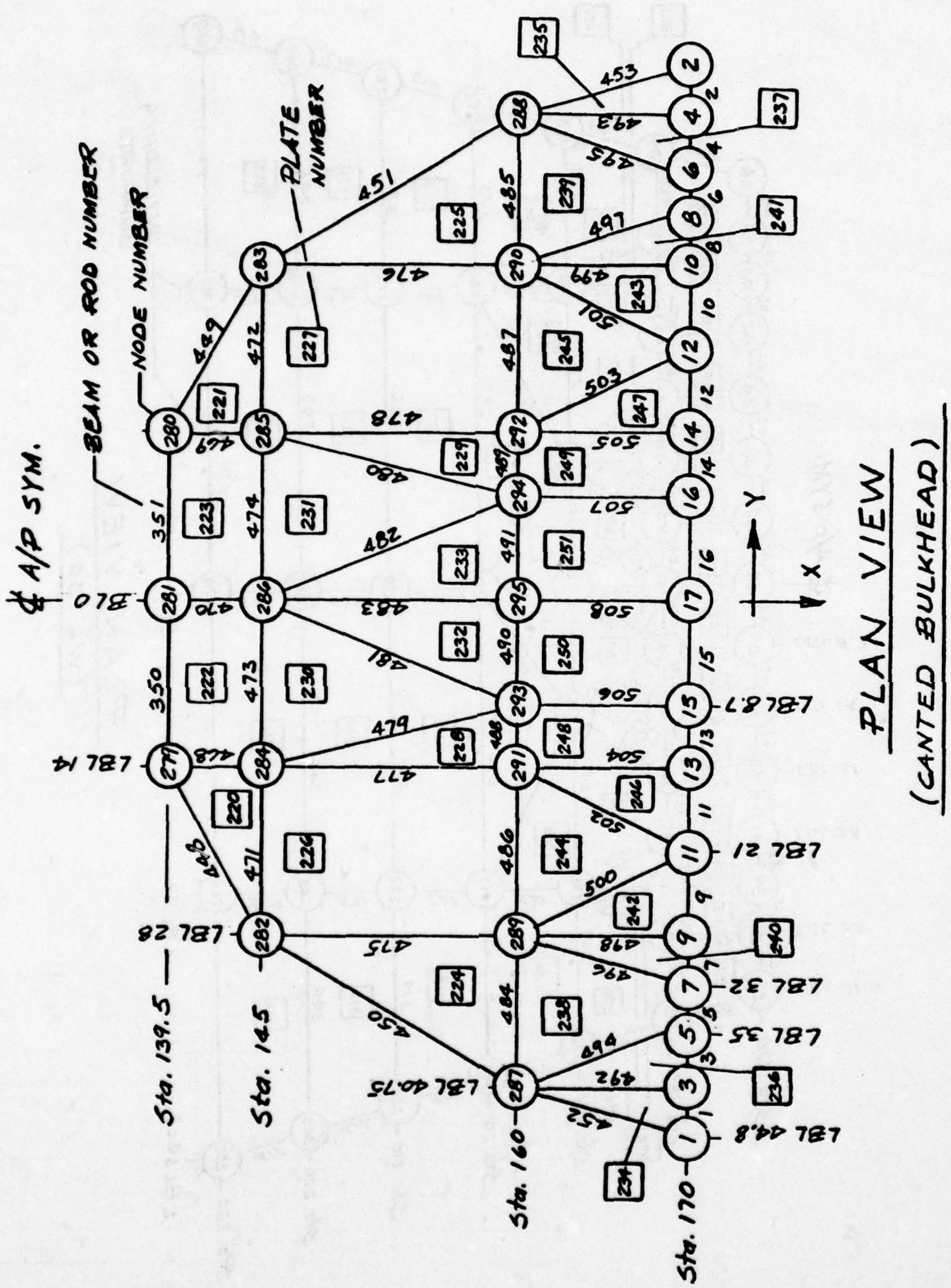
			REVISED	DATE		
ENGR.	C. Romero	11-10-77			CAST - FINITE ELEMENT COMPUTER MODEL	CAST
CHECK	BOLLINGER	11-29-77				Fig. 10
APR						
APR					BOEING	31



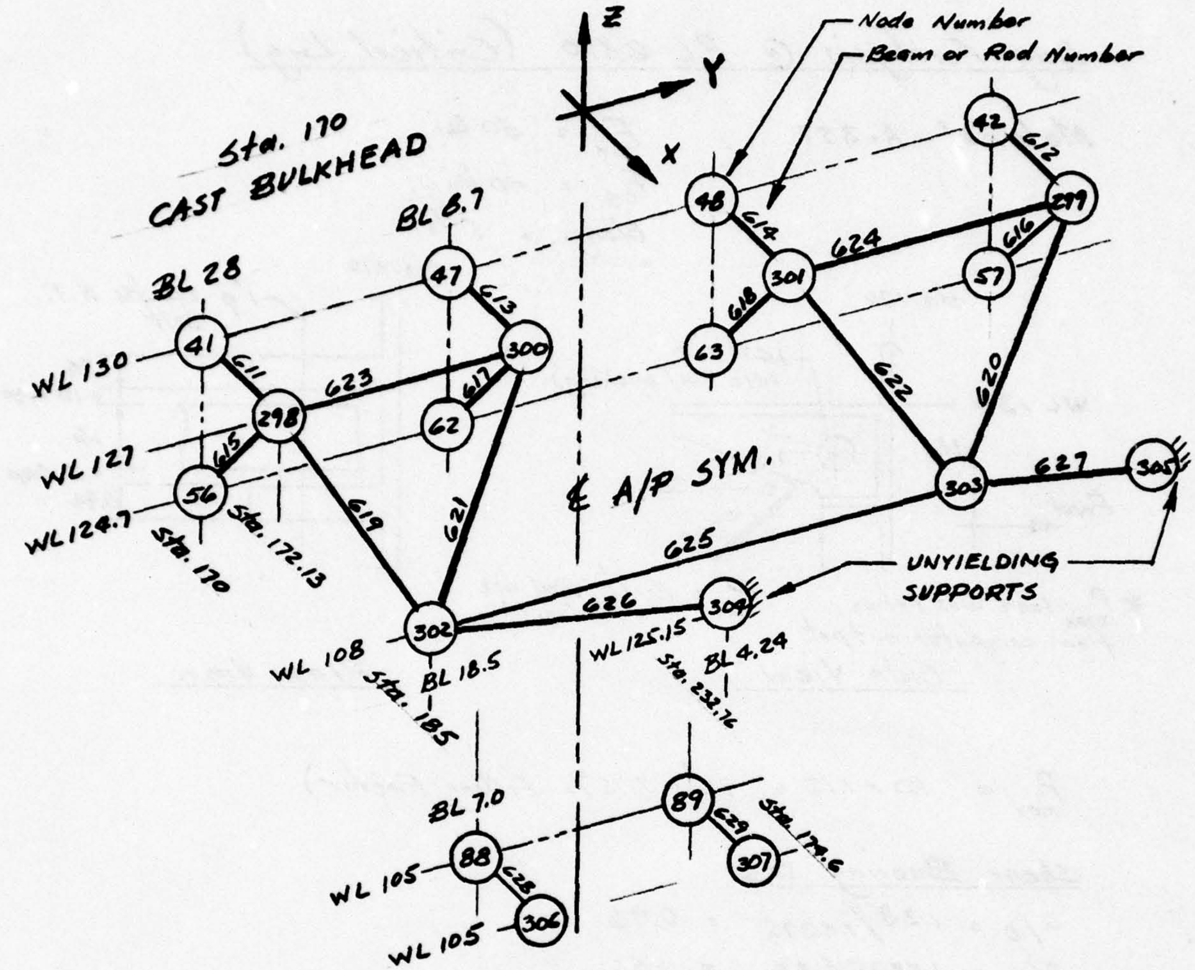
ENGR.	C. Pomero	11-10-77	REVISED	DATE	CAST- FINITE ELEMENT COMPUTER MODEL	CAST
CHECK	BOLLINGER	11-29-77				Fig. 11
APR						
APR					BOEING	32



			REVISED	DATE		
ENGR.	C. Romero	11-11-77			CAST- FINITE ELEMENT COMPUTER MODEL	CAST
CHECK	BOLLINGER	11-29-77				Fig. 12
APR						
APR					BOEING	33



ENGR	[signature]	11-11-77	REVISED	DATE	CAST- FINITE ELEMENT COMPUTER MODEL	CAST
CHECK	BOLLINGER	11-29-77				Fig. 13
APR						
APR					BOEING	34



LANDING GEAR BACK-UP STRUCTURE
& LANDING GEAR DOOR ACTUATOR SUPPORT

LOAD CONDITION	LOCATION & LOAD* APPLIED ON STRUCTURE					
	NODE 302			NODE 303		
	F_x	F_y	F_z	F_x	F_y	F_z
Landing - Spring Back	-31.84	0	79.5	-22.56	0	56.91
Boeing Side Load	-1.44	-22.5	98.89	-56.16	-22.5	-78.4
3 Point Braked Roll	-102.6	0	-3.8	-109.4	0	-37.7
Landing Gear Door	NODE 306			NODE 307		
Actuator Jammed Load	0	-27.0	-21.2	0	-11.5	36.0

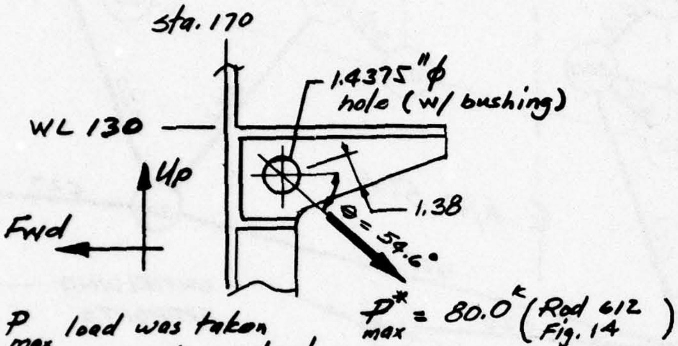
* All loads are in kips & ultimate.

ENGR.	C. Romero	11-14-77	REVISED	DATE	CAST - FINITE ELEMENT COMPUTER MODEL APPLIED LOADS	CAST
CHECK	BOLLINGER	11-29-77				Fig. 14
APR						
APR					BOEING	35

Lug Analysis @ BL 28.0 (Critical Lug)

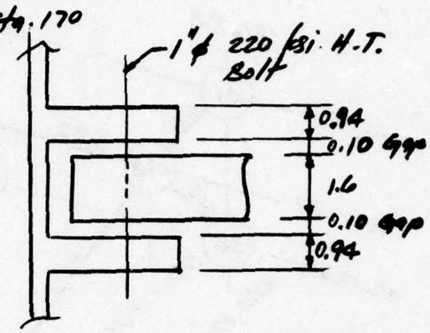
Material - A-357

$F_{tu} = 50$ ksi
$F_{ty} = 40$ ksi
Elong. = 5%



* P_{max} load was taken from computer output.

Side View



Plan View

$P_{max} = 80 \times 1.15 = 92^k$ (15% Fitting Factor)

Shear Bearing ▷1

$a/D = 1.38/1.4375 = 0.96$

$D/t = 1.4375/0.94 = 1.53$

$k_{br} = 0.77$ (Fig. 13 pg. 167)

$P_{brg} = k_{br} F_{tu} D t = 0.77 \times 50 \times 1.4375 \times 1.88 = 104.0^k$

$M.S. = \frac{104}{92} - 1 = \underline{+0.13}$

Tension ▷1 (Assume $W = 3.0$)

$W/D = 3.0/1.4375 = 2.09$

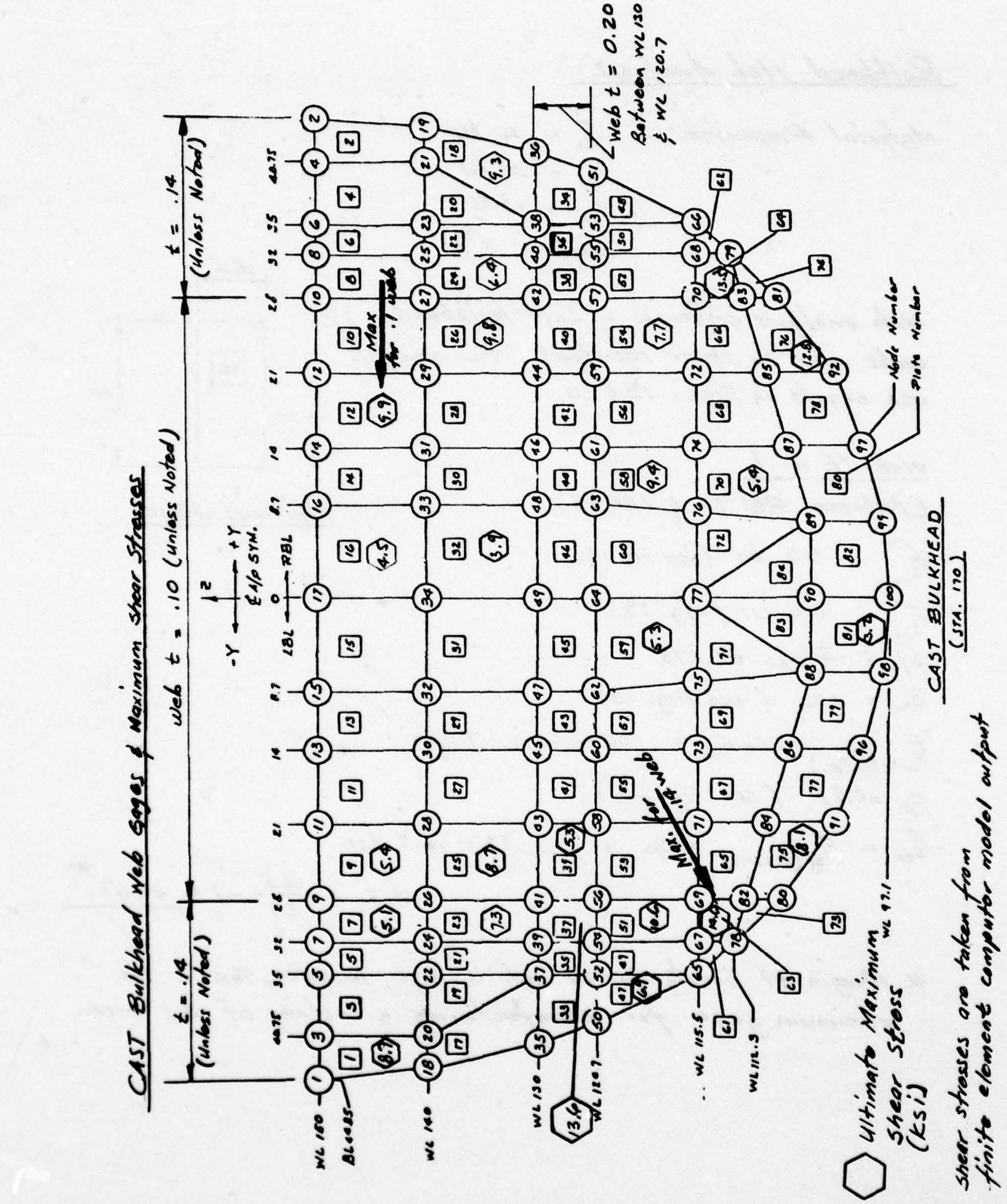
$k_t = 0.682$ (Fig. 12 pg. 166)

$P_t = k_t (W-D) F_{tu} t = 0.682 (3-1.4375) 50 \times 1.88 = 100.2^k$

$M.S. = 100.2/92 - 1 = \underline{+0.09}$

▷1 Lug Analysis Structural Bulletin 1.712 Product Eng. June 1953

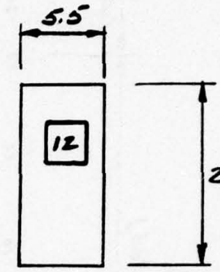
ENGR.	C. Romero	11-15-77	REVISED	DATE	CAST Bulkhead Critical Lug @ BL 28	CAST
CHECK	BOLLINGER	11-29-77				Fig. 15
APR						
APR					BOEING	36



ENGR.	C. Pomeroy	11-10-77	REVISED	DATE	CAST BULKHEAD	CAST
CHECK	BOLLINGER	11-29-77			Web GAGES & STRESSES	Fig. 16
APR						
APR					BOEING	37

<u>Bulkhead Web Analysis</u>

Material Properties – $F_{tu} = 40$ ksi
$F_{ty} = 30$ ksi
$F_{su} = 28$ ksi
Elong. = 3%



Critical Panel

Web analysis criteria – Cast bulkhead webs must be shear resistant. For analysis use charts in Figs. 19 & 20.

<u>Web $t = .1$</u>
(Between RBL 28 & LBL 28)

$f_{s_{max}} = 9.9$ ksi (see Fig. 16)

$F'_{s_{cr}} = 16.0$ ksi (Fig. 19)

$b/a = 5.5/20 = 0.275$

$C_a = 1.06$ (see Fig. 19)

$F_{s_{cr(elastic)}} = C_a F'_{s_{cr}} = 1.06 \times 16 = 17.0$ ksi.

$C_p = 0.97$ (see Fig. 20)

$F_{s_{cr}} = F_{s_{cr(elastic)}} \times C_p = 17 \times .97 = 16.5$ ksi.

$$M.S. = \frac{16.5}{9.9} - 1 = \underline{+0.67}\ *$$

* Margin of Safety for 0.1 web is high, however, this is the minimum gage for manufacturing a casting of this size.

ENGR.	A. Romero	11-14-77	REVISED	DATE	CAST Bulkhead Web ($t = 0.1$)	CAST
CHECK	BOLLINGER	11-29-77				Fig. 17
APR					BOEING	38
APR						

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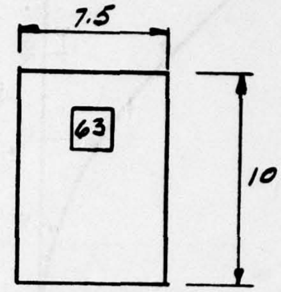
Bulkhead Web Analysis (Cont'd.)

Web $t = 0.14$

(Between BL 45 & BL 28)

For analysis use charts in Figs. 19 & 20



Critical Panel

f_s = 14.6 ksi (Fig. 16)

$F'_{s_{cr}}$ = 18.0 ksi (see Fig. 19)

$b/a = 7.5/10 = 0.75$

$C_a = 1.42$ (Fig. 19)

$F_{s_{cr}(elastic)} = C_a \times F_{s_{cr}} = 1.42 \times 18 = 25.6$ ksi

$C_p = 0.77$ (Fig. 20)

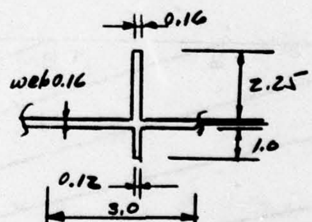
$F_{s_{cr}} = C_p \times F_{s_{cr}(elastic)} = 0.77 \times 25.6 = 19.7$ ksi.

Combine shear w/ Tension –

$P = 8.9^k$ (Bm 137 axial load Fig. 21)

$A = 0.96\ \square''$

$P/A = 8.9/0.96 = 9.3$ ksi < 40 ksi (F_{tu})



Cross-section (Bm 137)

$R_s = 14.6/19.7 = 0.74$

$R_t = 9.3/40 = 0.23$

$$\underset{(\text{shear + ten.})}{M.S.} = \frac{1}{\sqrt{R_s^2 + R_t^2}} - 1 = \underline{+0.29}$$

ENGR.	A. Romero	11-14-77	REVISED	DATE	CAST Bulkhead Web ($t = 0.14$)	CAST
CHECK	BOLLINGER	11-29-77				Fig. 18
APR					BOEING	39
APR						

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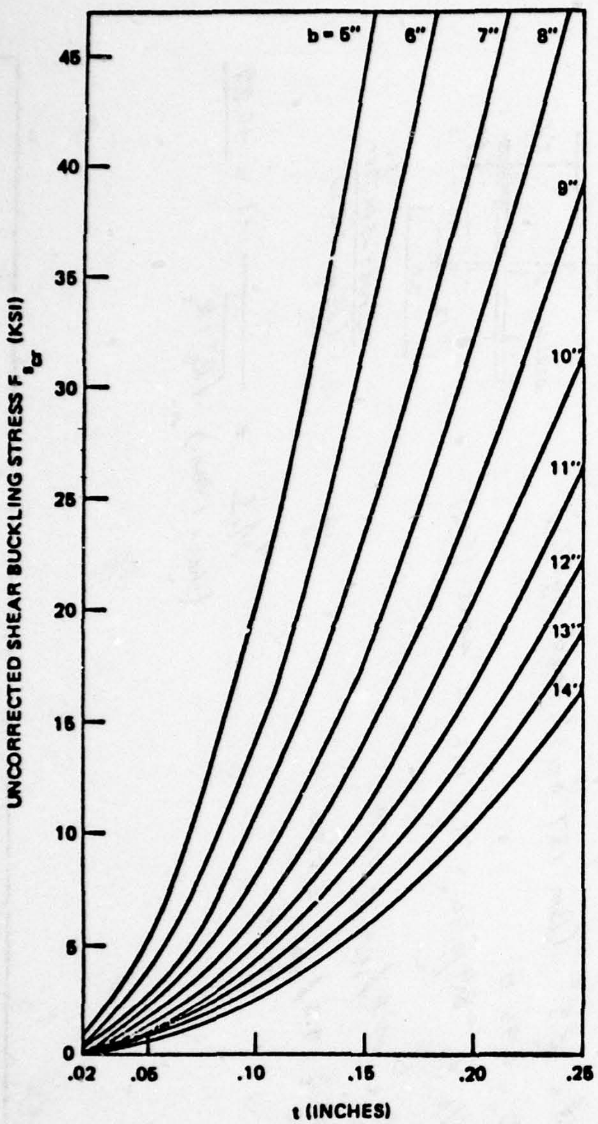
J15-047



SHEAR BUCKLING STRESS

$$F'_{s_{cr}} = (4.9)\,(10.4) \times 10^6 \left(\frac{t}{b}\right)^2$$

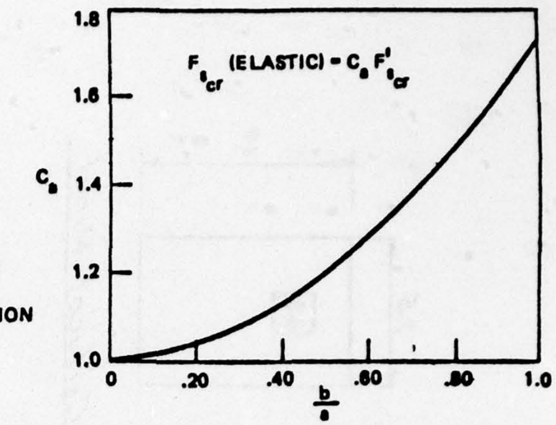
$$a \geq b$$

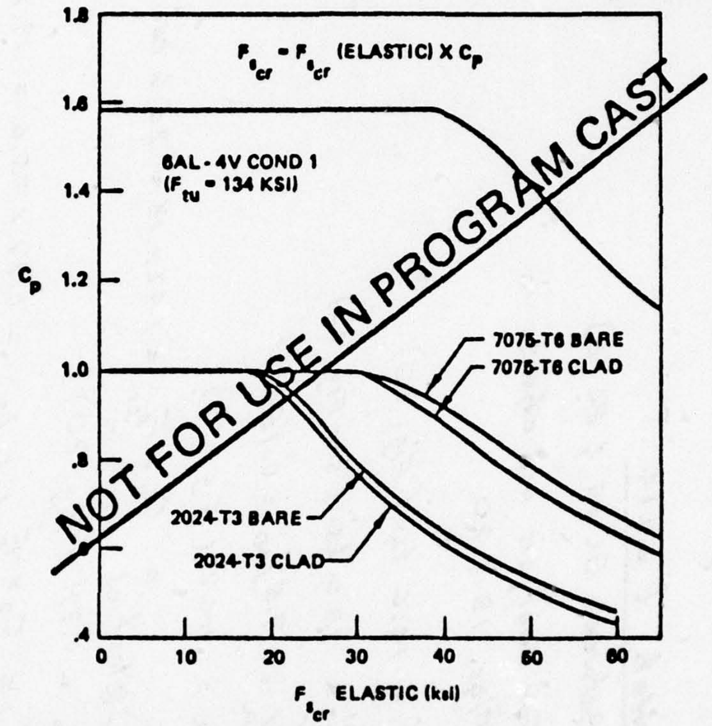
WHEN $h_r \geq \ell$: $a = h_r$, $b = \ell$

WHEN $\ell \geq h_r$: $a = \ell$, $b = h_r$

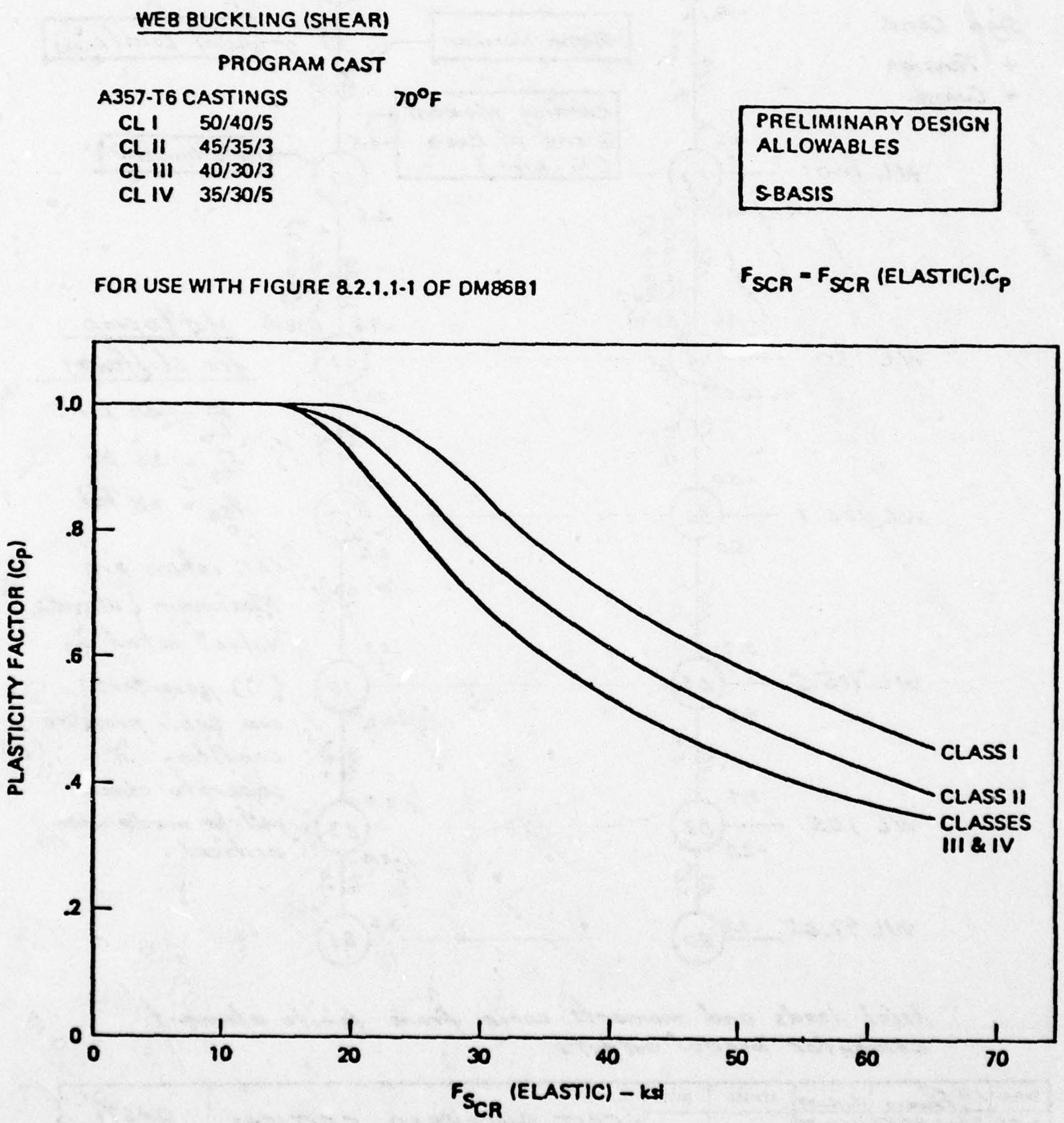
C_a = ASPECT RATIO CORRECTION FACTOR

C_p = MATERIAL AND PLASTICITY CORRECTION FACTOR



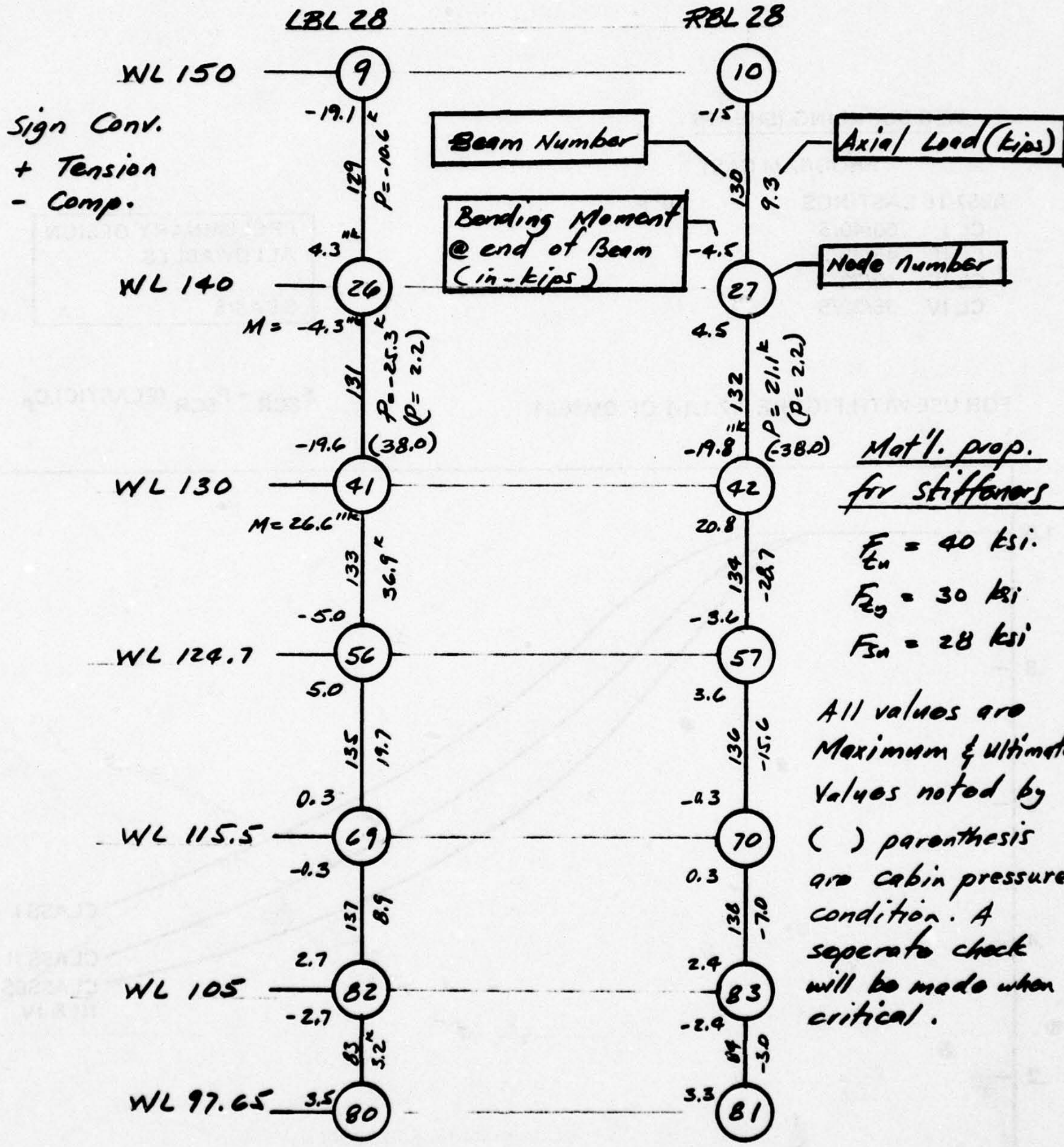


(Boeing Design Manual) *Figure 19. Web Ultimate Shear Stress (Shear Resistant Web Design)*



(Boeing Design Manual) *Figure 20. Shear Resistant Web Design*

Stiffeners @ LBL 28 & RBL 28 Axial Loads & Moments



Mat'l. prop. for stiffeners

F_{tu} = 40 ksi.

F_{ty} = 30 ksi

F_{su} = 28 ksi

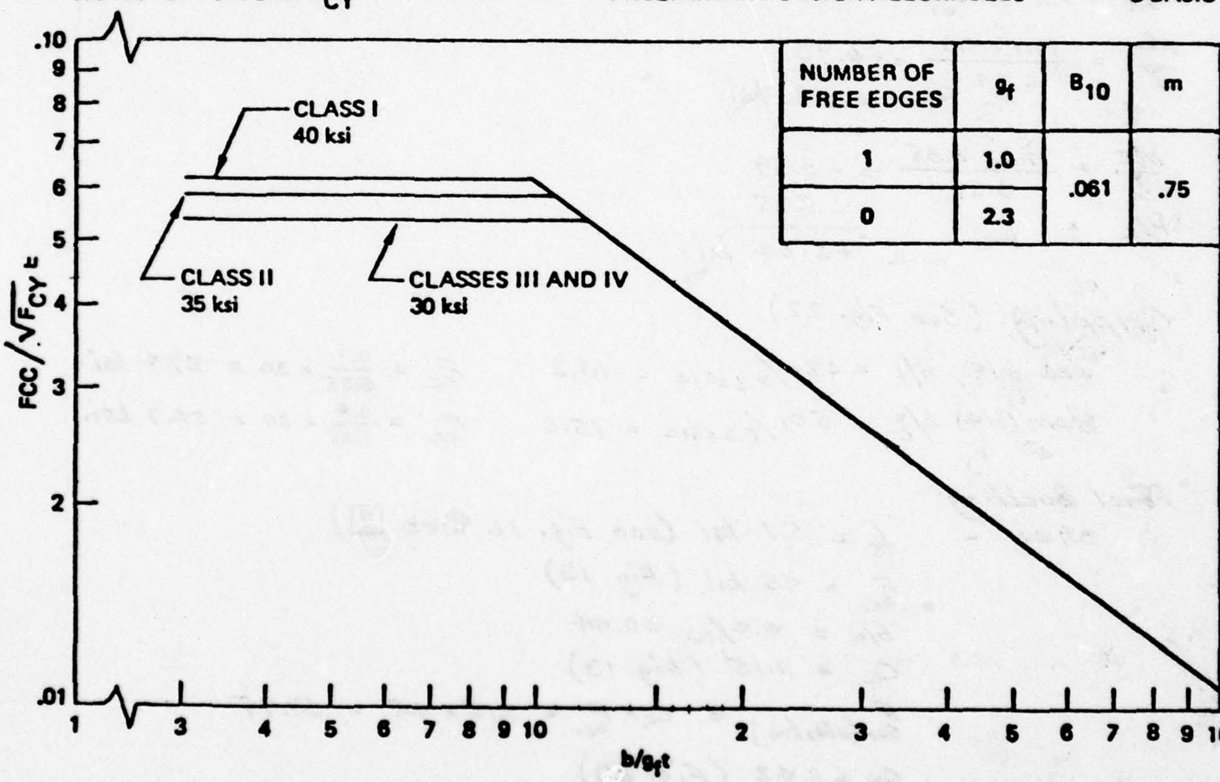
All values are Maximum & ultimate. Values noted by ( ) parenthesis are cabin pressure condition. A seperate check will be made when critical.

Axial loads and moments come from finite element computer model output.

ENGR.	C. Romero	11-16-77	REVISED	DATE	CAST BULKHEAD CRITICAL	CAST
CHECK	BOLLINGER	11-29-77			STIFFENER BL 28	Fig. 21
APR					BOEING	42
APR						

COMPRESSION CRIPPLING CURVES
A357.0 - T6 (CAST-XXXX) CASTING
ROOM TEMPERATURE
PRELIMINARY DESIGN ALLOWABLES S BASIS

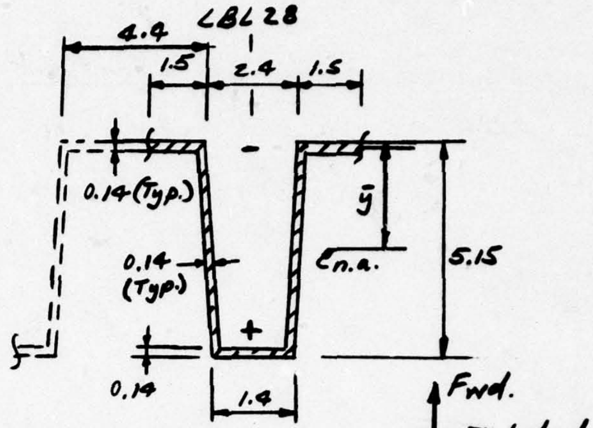
NOTE: CUTOFFS AT F_{CY}



NUMBER OF FREE EDGES	g_f	B_{10}	m
1	1.0	.061	.75
0	2.3		

Figure 22. Compression Crippling Curves

Section @ WL 150



PLAN VIEW

(section @ WL 150)

Section Properties -

$A = 1.98 \square''$

$\bar{y} = 2.3$

$I = 6.34 \text{ in}^4$

$P = -10.6^k$ } Bm 129

$M = 19.1^{"k}$ } see Fig. 21.

$P/A = -10.6/1.98 = -5.35$

$\frac{Mc}{I} = \frac{19.1 \times 2.3}{6.34} = -6.93$

-12.28 ksi.

$\frac{Mc}{I} = \frac{19.1 \times 2.85}{6.34} = +8.59$

$P/A = -5.35$

$+3.24$ ksi.

Crippling (see Fig. 22)

web (0.14) $b/t = 4.26/2.3 \times 0.14 = 13.2$ $F_{cc} = \frac{4.9}{5.35} \times 30 = 27.4$ ksi.

stem (0.14) $b/t = 5.01/2.3 \times 0.14 = 15.6$ $F_{cc} = \frac{4.4}{5.35} \times 30 = 24.7$ ksi.

Panel Buckling -

shear - $f_s = 5.1$ ksi (see Fig. 16, web $\boxed{7}$)

$F'_{s_{cr}} = 45$ ksi (Fig. 19)

$b/a = 4.4/10 = 0.44$

$C_a = 1.15$ (Fig. 19)

$F_{s_{cr}(elastic)} = C_a \times F'_{s_{cr}} = 1.15 \times 45 = 51.75$

$C_p = 0.42$ (Fig. 20)

$F_{s_{cr}} = C_p \times F_{s_{cr}(elastic)} = 0.42 \times 51.75 = 21.7$ ksi.

ENGR.	C. Romero	11-16-77	REVISED	DATE	CAST BULKHEAD CRITICAL STIFFENER BL 28	CAST
CHECK	BOLLINGER	11-29-77				Fig. 23
APR					BOEING	44
APR						

Section @ WL 150 (Cont'd.)

Panel Buckling -

Compression -

Aircraft Structures by Perry pg. 372 Fig. 14.25

$a/b = 10/4.4 = 2.27$

$k = 3.6$ (4 sides simply supported)

$F_{c_{cr}} = kE(t/b)^2$

$F_{c_{cr}} = 3.6 \times 10.4 \times 10^3 (.14/4.4)^2 = 37.9$ ksi > 30 ksi (F_{cy}) buckling is not critical

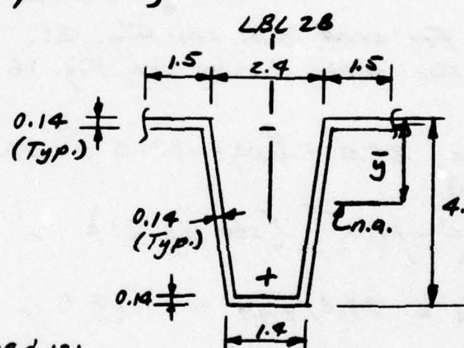
Combined Compression & Shear -

$R_c = f_c/F_{cc} = 12.28/24.7 = 0.497$

$R_s = f_s/F_{s_{cr}} = 5.1/21.7 = 0.235$

$$\underset{\text{(Comp. + shear)}}{M.S.} = \frac{1}{\sqrt{R_c^2 + R_s^2}} - 1 = \underline{+0.82}$$

Section @ WL 140



PLAN VIEW

(Section @ WL 140)

Section Properties -

$A = 1.66$ □"

$\bar{y} = 1.74$

$I = 3.38$ in^4

$P = \frac{10.6 + 25.3}{2} = 17.95^k$ } Bms 129 & 131 see Fig. 21.

$M = 4.3^{\text{''k}}$

$P/A = 17.95/1.66 = -10.8$

$\frac{Mc}{I} = \frac{4.3 \times 1.74}{3.38} = \frac{-2.2}{-13.0}$ ksi. < 27.4 ksi. (F_{cc} prev. pg.)

$f_s = 7.3$ ksi (Fig. 16, web $\boxed{23}$) < 21.7 ksi ($F_{s_{cr}}$ prev. pg.)

$R_s = f_s/F_{s_{cr}} = 7.3/21.7 = 0.336$

$R_c = f_c/F_{cc} = 13/27.4 = 0.474$

$$\underset{\text{(comp + shear)}}{M.S.} = \frac{1}{\sqrt{R_s^2 + R_c^2}} - 1 = \underline{+0.72}$$

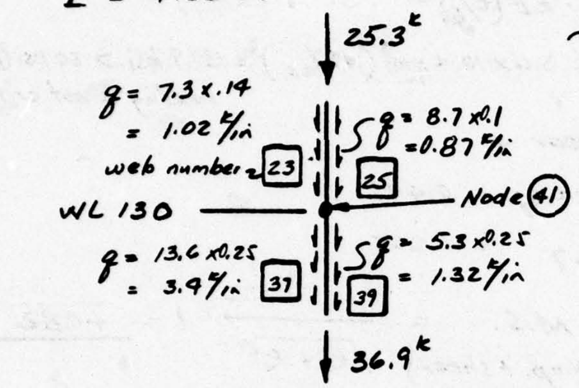
ENGR.	C. Romero	11-16-77	REVISED	DATE	CAST BULKHEAD CRITICAL	CAST
CHECK	BOLLINGER	11-29-77			STIFFENER BL 28	Fig. 24
APR					BOEING	
APR						45

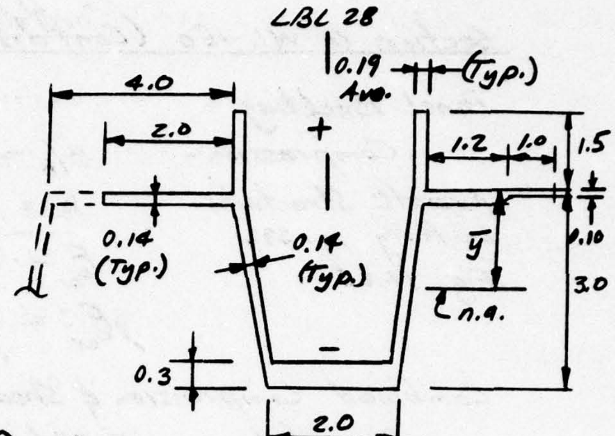
Section @ WL 130

$A = 2.47 \ \square''$

$\bar{y} = 0.95$

$I = 4.88 \ in^4$





PLAN VIEW
(Section @ WL 130)

For axial loads see Fig. 21.
For shear stresses see Fig. 16.

$P_{(@ WL 130)} = 25.3 + (1.02 + .87)\,5 = 34.8^k$

$M_{(@ WL 130)} = -19.6^{\,"k}$ (see Fig. 21)

$P/A = 34.8/2.47 = -14.1$ $\qquad -14.1$

$\frac{Mc}{I} = \frac{19.6 \times 2.05}{4.88} = \frac{-8.2}{\Sigma = -22.3 \ ksi.} \qquad + \frac{Mc}{I} = \frac{19.6 \times 2.45}{4.88} = \frac{+9.8}{-4.3 \ ksi}$

$f_s = 1.02/0.3 = 3.4 \ ksi. < F_{su} = 28 \ ksi$

Combined compression & shear -

$R_c = f_c/F_{cy} = 22.3/30 = 0.743$

$R_s = f_s/F_{su} = 3.4/28 = 0.121$

$M.S._{(Extreme\ fiber)} = \frac{1}{\sqrt{R_c^2 + R_s^2}} - 1 = \underline{+0.32}$

ENGR.	A. Romero	11-16-77	REVISED	DATE	CAST BULKHEAD CRITICAL STIFFENER BL 28	CAST
CHECK	BOLLINGER	11-23-77				Fig. 25
APR					BOEING	46
APR						

Section @ WL 130 (Cont'd.)

Check location 0.3 from extreme fiber (see sketch prev. pg.) -

$$\frac{Mc}{I} = \frac{19.6 \times 1.75}{4.88} = -7.0$$

$$P/A = \text{prev. pg.} = \underline{-14.1}$$

$$-21.1 \text{ ksi.} < 30 \text{ ksi.} (F_{cy})$$

$$f_s = 1.02/0.14 = 7.3 \text{ ksi.} \text{ (prev. pg.)} < 28 \text{ ksi.} (F_{su})$$

Combined comp. & shear -

$$R_c = 21.1/30 = 0.703$$

$$R_s = 7.3/28 = 0.261$$

$$\text{M.S.} = \frac{1}{\sqrt{R_c^2 + R_s^2}} - 1 = \underline{+.33}$$

(.3 from extreme fiber)

Check Pressure Case -

$$P = 2.2^{k}$$

$$M = 38.0^{\text{ik}}$$

Bm 132
See Fig. 21.
Note: moment is reversed from previous critical condition. Shear is small, neglect.

$$P/A = 2.2/2.47 = 0.9$$

$$\frac{Mc}{I} = \frac{38 \times 2.05}{4.88} = \underline{16.0}$$

$$16.9 \text{ ksi.} < 40 \text{ ksi.} (F_{tu})$$

$$P/A = 2.2/2.47 = +0.9$$

$$\frac{Mc}{I} = \frac{38 \times 2.45}{4.88} = \underline{-19.1}$$

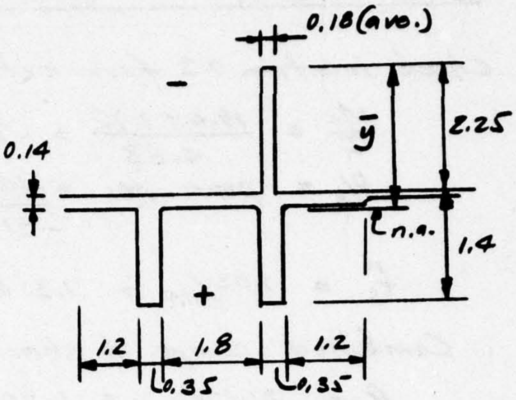
$$-18.2 \text{ ksi} < 30 \text{ ksi} (F_{cy})$$

$$\text{M.S.} = \frac{30}{18.2} - 1 = \underline{+0.64}$$

(pressure case)

ENGR.	C. Kinsoa	11-17-77	REVISED	DATE	CAST BULKHEAD CRITICAL STIFFENER BL 28	CAST Fig. 26
CHECK	BOLLINGER	11-29-77				
APR						
APR					BOEING	47

Section @ WL 124.7



Plan View
(Section @ WL 124.7)

$A = 1.97\ \square''$

$\bar{y} = 2.39$

$I = 1.28\ in^4$

$P = -15.6^k$ } Bm 136
$M = 3.6''^k$ } see Fig. 21.

$P/A = 15.6/1.97 = -7.9$

$\frac{Mc}{I} = \frac{3.6 \times 2.39}{1.28} = \underline{-6.7}$

-14.6 ksi

Crippling – (Fig. 22.)

stem (.18) $\quad b/t = 2.25/.18 = 12.5 \qquad F_{cc} = 5.1/5.33 \times 30 = 28.6$ ksi.

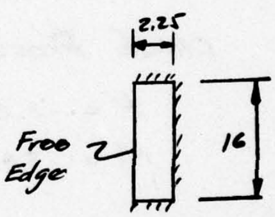
Buckling – ▷[1] (pg. 372 Fig. 14.25)

$a/b = 16/2.25 = 7.1$

$k = 0.385$

$F_{c_{cr}} = kE(t/b)^2 = 0.385 \times 10.4 \times 10^3 (.18/2.25)^2$

$= 25.6$ ksi



simply supported 3-sides

$\underset{(comp.)}{M.S.} = \frac{25.6}{14.6} - 1 = \underline{+0.75}$

$P = 19.7^k$ } Bm 135
$M = 5.0^k$ } see Fig. 21. $\qquad$ Note – Moment is reverse from Bm 136

$P/A = 19.7/1.97 = 10.0$

$\frac{Mc}{I} = \frac{5 \times 2.39}{1.28} = \underline{9.3}$

19.3 ksi < 40 ksi (F_{tu})

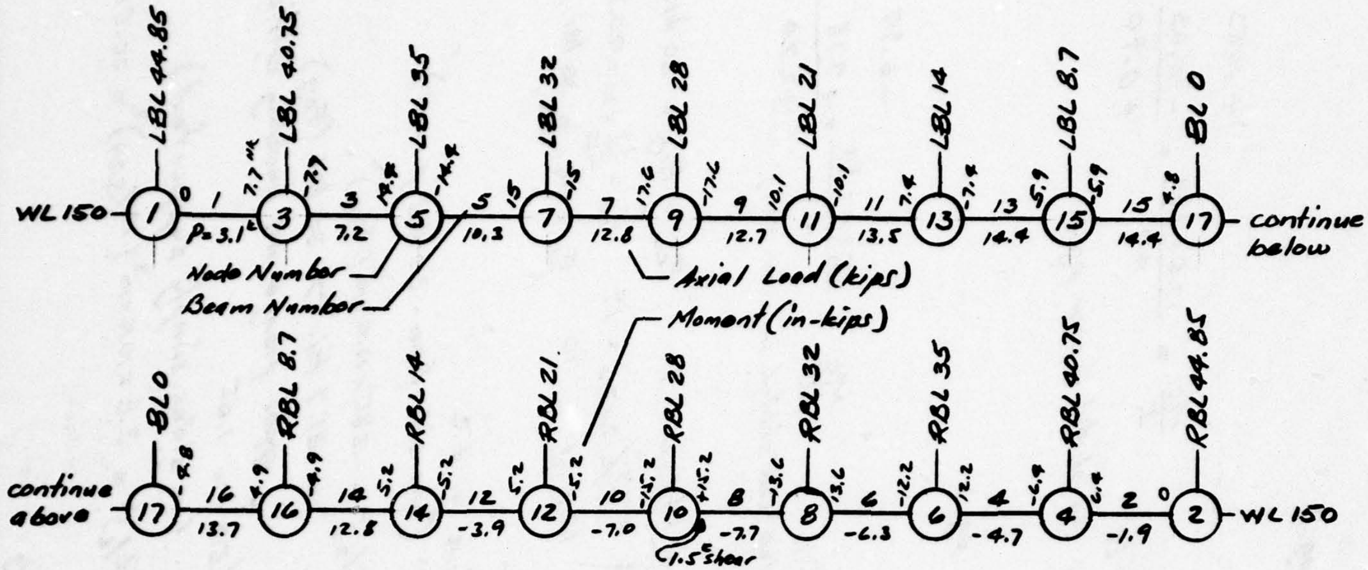
$\underset{(tension)}{M.S.} = \frac{40}{19.3} - 1 = \underline{high}$

▷[1] Aircraft structures by D. J. Perry

ENGR.	C. Ramon	11-17-77	REVISED	DATE	CAST BULKHEAD CRITICAL	CAST
CHECK	BOLLINGER	11-29-77			STIFFENER BL 28	Fig. 27
APR						
APR					BOEING	48

D1 5007 2070 ORIG. 6/73 $\qquad$ J18-047

Horizontal Beam @ WL 150



Horizontal Beam @ WL 150
(See Fig. 6 CAST Bulkhead)

Axial loads and moments come from finite element computer model output.

Mat'l. Prop. for hor. Bm.

F_{tu} = 40 ksi

F_{ty} = 30 ksi

F_{su} = 28 ksi

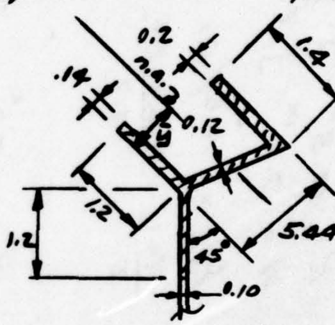
All values are maximum & ultimate.

Section Properties

A = 1.11 □"

$\bar{y}$ = 2.84

I = 4.7 in^4



Cross-Section
Horizontal Beam

ENGR.	C. Romero	11-17-77	REVISED	DATE	Horizontal Beam @ WL 150
CHECK	BOLLINGER	11-29-77			CAST
APR					Fig. 28
APR					BOEING
					49

Horizontal Beam @ WL 150 (cont'd.)

$P = 12.8^{k}$ } Bm 7
$M = 17.6^{\prime\prime k}$ } (see prev. pg.)

$P/A = 12.8/1.11 = 11.53$ $\qquad$ $+11.53$

$\frac{Mc}{I} = \frac{17.6 \times 2.6}{4.7} = \underline{9.74}$ $\qquad$ $\frac{Mc}{I} = \frac{17.6 \times 2.84}{4.7} = \underline{-10.63}$

$+21.27$ ksi $\qquad$ $+0.90$ ksi

(Ten. on top see sketch in prev. pg.)

$P = -7.7^{k}$ } Bm 8
$M = 15.2^{\prime\prime k}$ } (see prev. pg.)

$P/A = 7.7/1.11 = -6.94$ $\qquad$ -6.94

$\frac{Mc}{I} = \frac{15.2 \times 2.6}{4.7} = \underline{-8.41}$ $\qquad$ $\frac{Mc}{I} = \frac{15.2 \times 2.84}{4.7} = \underline{+9.18}$

-15.35 ksi. $\qquad$ $+2.24$ ksi

(comp. on top see sketch in prev. pg.)

Crippling (Fig. 22)

top flange ($t = 0.2$) $\quad b/t = 1.4/0.2 = 7$ $\quad F_{cc} = F_{cy} = 30$ ksi

web ($t = 0.12$) $\quad b/t = 5.27/0.12 \times 2.3 = 19$ $\quad F_{cc} = \frac{3.7}{5.35} \times 30 = 20.7$ ksi

lower flange ($t = 0.12$) $\quad b/t = 1.2/0.12 = 10$ $\quad F_{cc} = F_{cy} = 30$ ksi.

Buckling ([1] pg. 372 Fig. 14.25) –

upper flange – $a/b = 8.7/1.4 = 6.2$

$k = .385$ (one side free – 3 sides pinned)

$F_{c_{cr}} = kE(t/b)^2 = .385 \times 10.4 \times 10^3 (.2/1.4)^2$

$= 81.7$ ksi. > 30 ksi. (F_{cy})

upper flange not buckling critical

web – $a/b = 8.7/5.27 = 1.65$

$k = 3.8$ (4 sides simply supported)

$F_{c_{cr}} = kE(t/b)^2 = 3.8 \times 10.4 \times 10^3 (.12/5.27)^2 = 20.5$ ksi

[1] Aircraft Structures by Perry

Horizontal Beam @ WL 150 (cont'd.)

$P = 12.8^{k}$, $M = 17.6^{''k}$ } Bm 7 (see prev. pg.)

$P/A = 12.8/1.11 = 11.53$

$\frac{Mc}{I} = \frac{17.6 \times 2.6}{4.7} = 9.74$

21.27 ksi < 40 ksi

upper flange stress, see sketch in Fig. 28

M.S. (upper flange) $= \frac{40}{21.27} - 1 =$ high

$P = -7.7^{k}$, $M = 15.2^{''k}$ } Bm 8 (see prev. pg.)

$P/A = 7.7/1.11 = -6.94$

$\frac{Mc}{I} = \frac{15.2 \times 2.6}{4.7} = -8.41$

-15.35 ksi { upper flange stress, see sketch in Fig. 28

Web Crippling - (Fig. 22) $\quad b/t = 5.27/0.12 \times 2.3 = 19 \qquad F_{cc} = \frac{3.7}{5.35} \times 30 = 20.7$ ksi.

Web Buckling compression (1 pg. 372 Fig. 14.25)

$a/b = 7.0/5.27 = 1.33$

$k = 3.7$ (4 sides simply supported)

$F_{c_{cr}} = kE(t/b)^2 = 3.7 \times 10.4 \times 10^3 (0.12/5.27)^2 = 20.0$ ksi.

Web Buckling Shear (see Figs. 19 & 20)

$t = 0.12 \quad F'_{s_{cr}} = 27$ ksi

$b/a = 5.27/7.0 = 0.75 \qquad C_a = 1.44$

$F_{s_{cr}(elastic)} = C_a \times F'_{s_{cr}} = 1.44 \times 27 = 38.9$ ksi $\qquad C_p = 0.56$

$F_{s_{cr}} = C_p \times F_{s_{cr}(elastic)} = 0.56(38.9) = 21.8$ ksi.

Combined Compression & shear - $\qquad f_s = 1.5/5.27 \times .12 = 2.4$ ksi (Fig. 28, Bm No. 8)

$R_c = f_c/F_{c_{cr}} = 6.94/20 = 0.347$

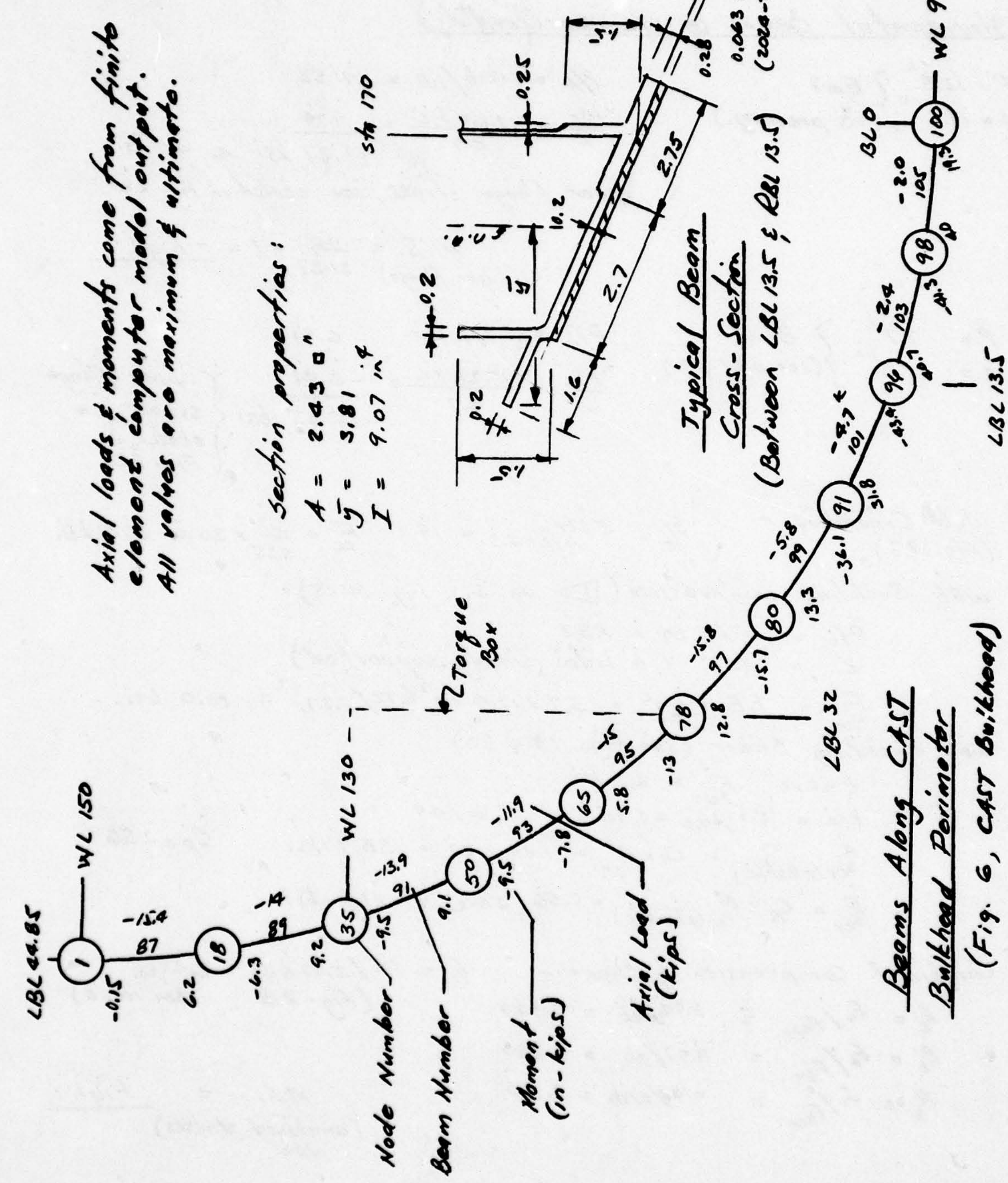
$R_b = f_b/F_{tu} = 8.41/30 = 0.280$

$R_s = f_s/F_{s_{cr}} = 2.4/21.8 = 0.110$

M.S. (combined stresses) web $=$ high

1 Aircraft Structures by Perry

ENGR.	[signature]	11-18-77	REVISED	DATE	Horizontal Beam @ WL 150	CAST
CHECK	BOLLINGER	11-29-77				Fig. 30
APR						
APR					BOEING	51



			REVISED	DATE		
ENGR.	[signature]	11-14-77			CAST- Bulkhead Perimeter Chord	CAST
CHECK	BOLLINGER	11-29-77				Fig. 31
APR						
APR					BOEING	52

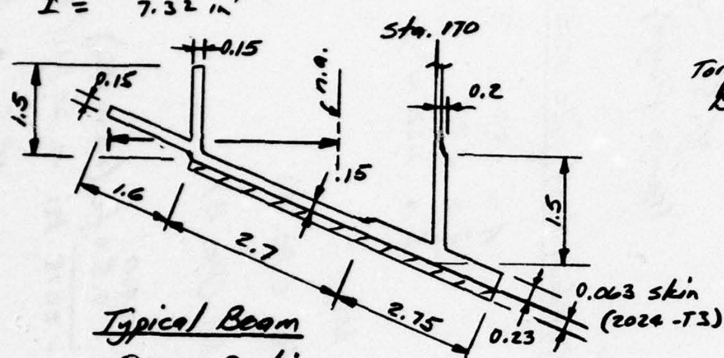
Axial loads and moments come from finite element computer model output.
All values are maximum & ultimate.

Section properties:

$A = 1.98 \text{ in}^2$

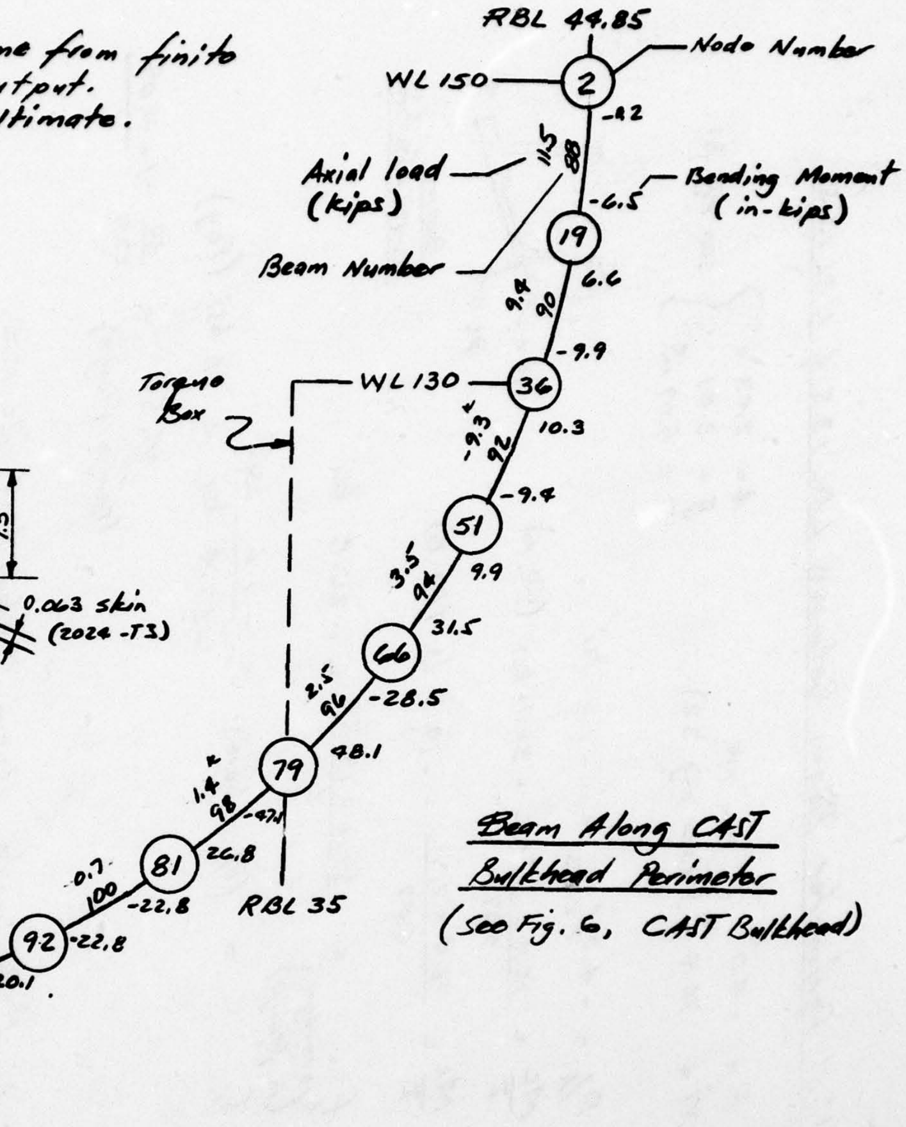
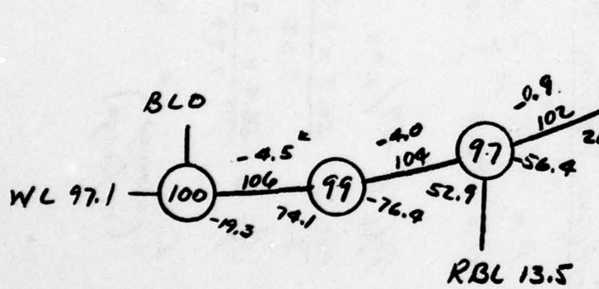
$\bar{y} = 3.87$

$I = 7.32 \text{ in}^4$



Typical Beam Cross-Section

(Outboard of LBL 13.5 & RBL 13.5)

Beam Along CAST Bulkhead Perimeter

(See Fig. 6, CAST Bulkhead)

			REVISED	DATE		
ENGR.	C. Kanas	11-18-77			CAST-Bulkhead Perimeter Chord	CAST
CHECK	BOLLINGER	11-29-77				Fig. 32
APR						
APR					BOEING	53

D1 5007 2070 ORIG. 6/73

J15-047

Critical Perimeter Beam Between LBL 13.5 & RBL 13.5

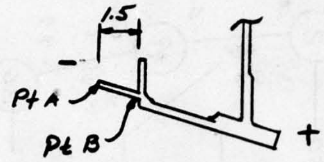
$P = -4.0^k$, $M = 76.4^{''k}$ } Bm 104 (see Fig. 32)

$A = 2.43\ \square''$, $\bar{y} = 3.81$, $I = 9.07\ in^4$ } see Fig. 31.

$P/A = -4.0/2.43 = -1.6$ ksi

$\frac{Mc}{I} = \frac{76.4 \times 3.81}{9.07} = -32.1$ ksi (Pt. A)

$\frac{Mc}{I} = \frac{76.4 \times 2.31}{9.07} = -19.5$ ksi (Pt. B)



Beam Cross-Section

$f_{b\,(\text{average in flange})} = \frac{32.1 + 19.5}{2} = -25.8$ ksi.

$f_c = (P/A \text{ above}) = \underline{-1.6}$ ksi.

-27.4 ksi < 30 ksi (F_{cy})

M.S. (comp. flange) $= \frac{30}{27.4} - 1 = \underline{+0.09}$

Critical Perimeter Beam Outboard of BL 13.5

$P = -0.9^k$, $M = 56.4^{''k}$ } Bm 102 see Fig. 32.

$A = 1.98\ \square''$, $\bar{y} = 3.87$, $I = 7.32\ in^4$ } see Fig. 32

$P/A = -0.9/1.98 = -0.5$ ksi.

$\frac{Mc}{I} = \frac{56.4 \times 3.87}{7.32} = -29.8$ ksi (Pt. A)

$\frac{Mc}{I} = \frac{56.4 \times 2.37}{7.32} = -18.3$ ksi (Pt. B)

$f_{b\,(\text{average in flange})} = \frac{29.8 + 18.3}{2} = -24.0$

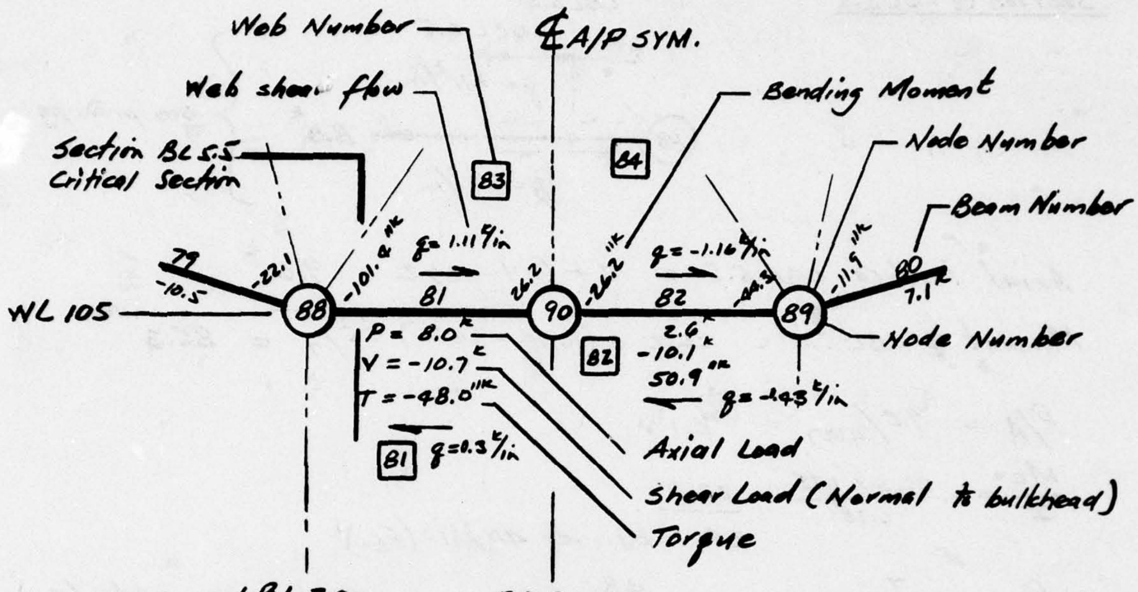
$\underline{0.5} = f_c$ (above P/A)

-24.5 ksi < 30 ksi (F_{cy})

M.S. (comp. flange) $= \frac{30}{24.5} - 1 = \underline{+0.22}$

			REVISED	DATE		
CALC	C. Guan	11-19-77			CAST- Bulkhead Perimeter Chord	CAST
CHECK	Bollinger	11-29-77				Fig. 33
APR					BOEING	54
APR						

Torque Box @ WL 105 - Landing Gear Door Actuator Support



Torque Box Segment of CAST Bulkhead

All values come from finite element computer model output.
All values are maximum & ultimate.

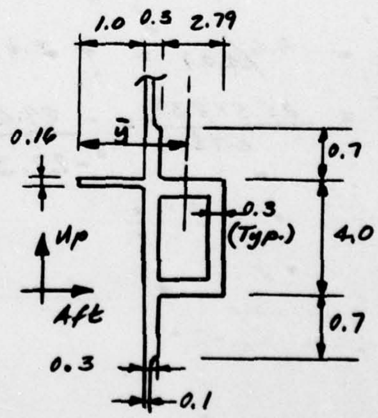
Check Section @ LBL 5.5

$A = 4.47\ \square''$

$\bar{y} = 2.34$

$I = 6.78\ in^4$

$J = 9.85$

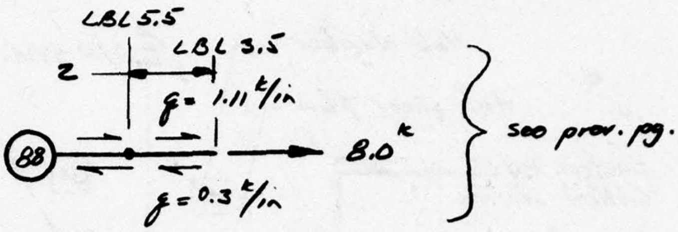


Section @ BL 5.5

			REVISED	DATE		
ENGR.	C. Rowan	11-21-77			Torque Box @ WL 105	CAST
CHECK	BOLLINGER	11-29-77			L. G. Door Actuator Support	Fig. 34
APR					BOEING	55
APR						

Torque Box @ WL 105 (Cont'd.)

Section @ LBL 5.5



Axial load @ LBL 5.5 $= 8 + (1.11 - .3)\,2 = 9.6^{k}$

Moment @ LBL 5.5 $= 26.2 + (101.4 - 26.2)\,5.5/7 = 85.3^{"k}$

$$P/A = 9.6/4.47 = 2.1$$

$$\frac{Mc}{I} = \frac{85.3 \times 1.75}{6.78} = \underline{22.0}$$

$$24.1 \text{ ksi} < 40 \text{ ksi} \; (F_{tu})$$

$$f_s = \frac{T}{2t(a-t)(b-t)} = \frac{48}{2 \times .3(4-.3)(3.09-.3)} = 7.7 \text{ ksi} < 28 \text{ ksi} \; (F_{su})$$

Combined stresses –

$$R_t = 24.1/40 = 0.603$$

$$R_s = 7.7/28 = 0.275$$

$$\underset{\text{(tension)}}{M.S.} = \frac{1}{\sqrt{R_t^2 + R_s^2}} - 1 = \underline{+0.50}$$

$$P/A = 9.6/4.47 = +2.1$$

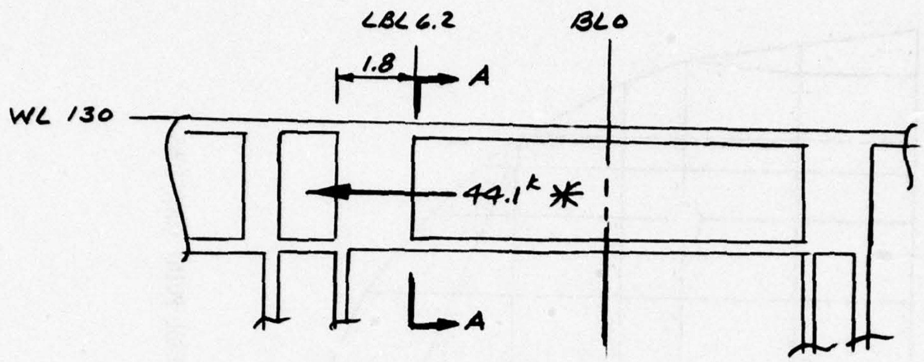
$$\frac{Mc}{I} = \frac{85.3 \times 2.34}{6.78} = -\underline{29.4}$$

$$-27.3 \text{ ksi} < 30 \text{ ksi} \; (F_{cy})$$

$$\underset{\text{(Comp.)}}{M.S.} = \frac{30}{27.3} - 1 = \underline{+0.10}$$

			REVISED	DATE		
ENGR.	A. Romero	11-21-77			Torque Box @ WL 105	CAST
CHECK	BOLLINGER	11-29-77			L.G. Door Actuator Support	Fig. 35
APR					BOEING	56
APR						

Lug Back-up structure @ BL 8.7



Lug is critical for lateral load

section properties of A-A -

$A = 4.53 \square''$

$\bar{y} = 3.3$

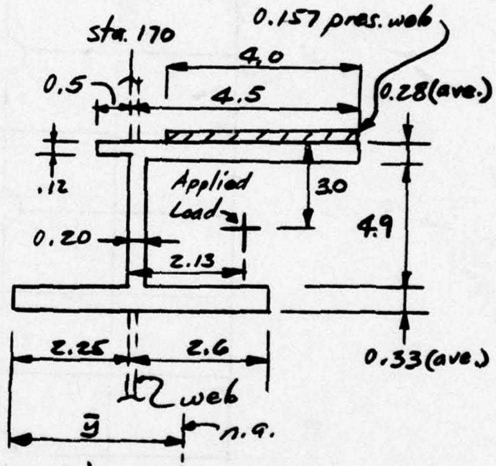
$I = 11.3 \text{ in}^4$

$M = 44.1\,(4.38 - 3.3) = 47.63''^{k}$

$P/A = 44.1/4.53 = +9.7$

$\frac{Mc}{I} = \frac{47.63 \times 3.45}{11.3} = \underline{+14.5}$

± 24.2 ksi (load is reversible)



A-A

$\underset{(\text{comp.})}{M.S.} = \frac{30}{24.2} - 1 = \underline{+0.24}$

* Load comes from finite element computer model Sum V_2 (lateral Bm shear) of Bms 613 & 617

ENGR.	C. Romero	11-22-77	REVISED	DATE	Lug Back-up structure for Lug @ BL 8.7	CAST
CHECK	BOLLINGER	11-29-77				Fig. 36
APR						
APR					BOEING	57

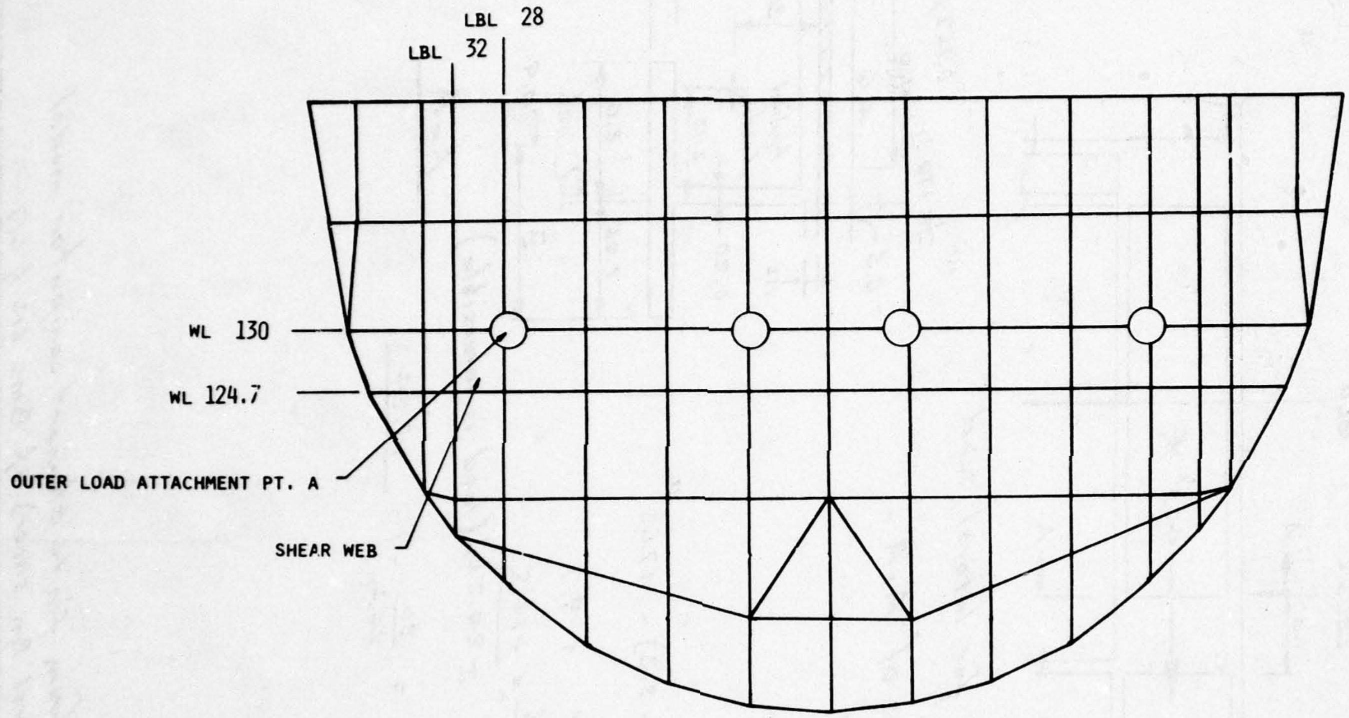


FIGURE 37 DAMAGE TOLERANCE CRITICAL CONTROL POINT LOCATIONS

A third detail/flaw combination consisting of a corner crack at a stiffener on the pressure web was considered; however, finite element analysis showed detail stresses to be uncritical.

According to the requirements of MIL-A-83444, the cast bulkhead is classified as slow crack growth structure and in-service noninspectable.

a. Initial Flaw Assumption

Initial flaw assumptions were made in accordance with MIL-A-83444 requirements for slow crack growth structure:

- o 0.05-inch radius corner flaw at the side of a hole (fig. 38)
- o Semicircular surface flaw with a length (2c) equal to 0.25 inch and a depth (a) equal to 0.125 inch (fig. 39)

b. Material Properties

Crack growth rate (da/dn) for A357 cast aluminum was obtained from fatigue crack growth rate testing using thin compact tension specimens (Test Group A, Specimens ASEN 1 - ASEN 8, ref. 1). A least-squares fit of the data shown in figure 40 was calculated using the Erdogan equation:

$$da/dn = (4.76 \times 10^{-11})\ (D)\ (K_{max})^{4.70}$$

$$\text{where } D = \begin{cases} 0 & ; \quad R > 1 \\ (1-R)^{3.70} & ; \quad 0 \leq R < 1 \\ (1-R/2) & ; \quad -1 < R \leq 0 \\ 1.5 & ; \quad R < -1 \end{cases}$$

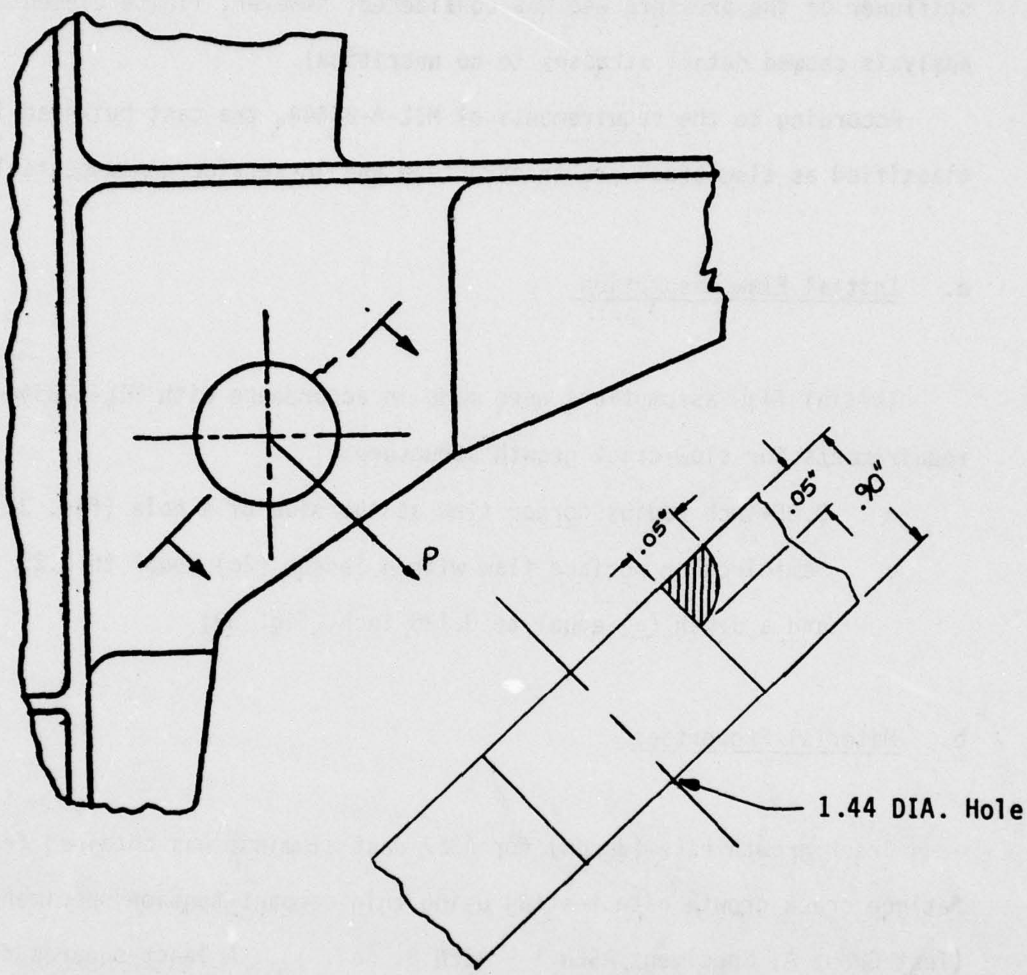
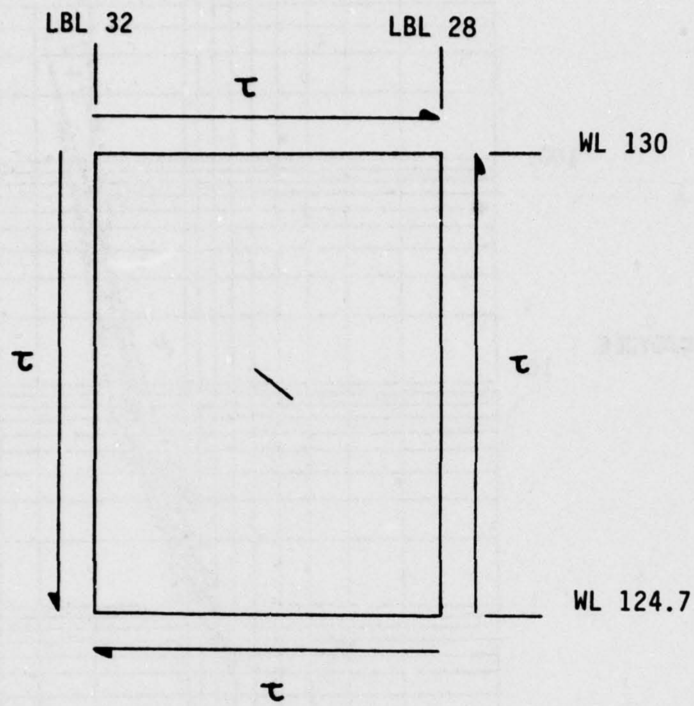


FIGURE 38. LOAD ATTACHMENT POINT A INITIAL FLAW LOCATION



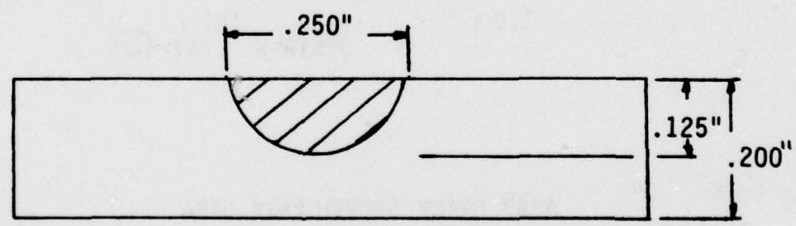
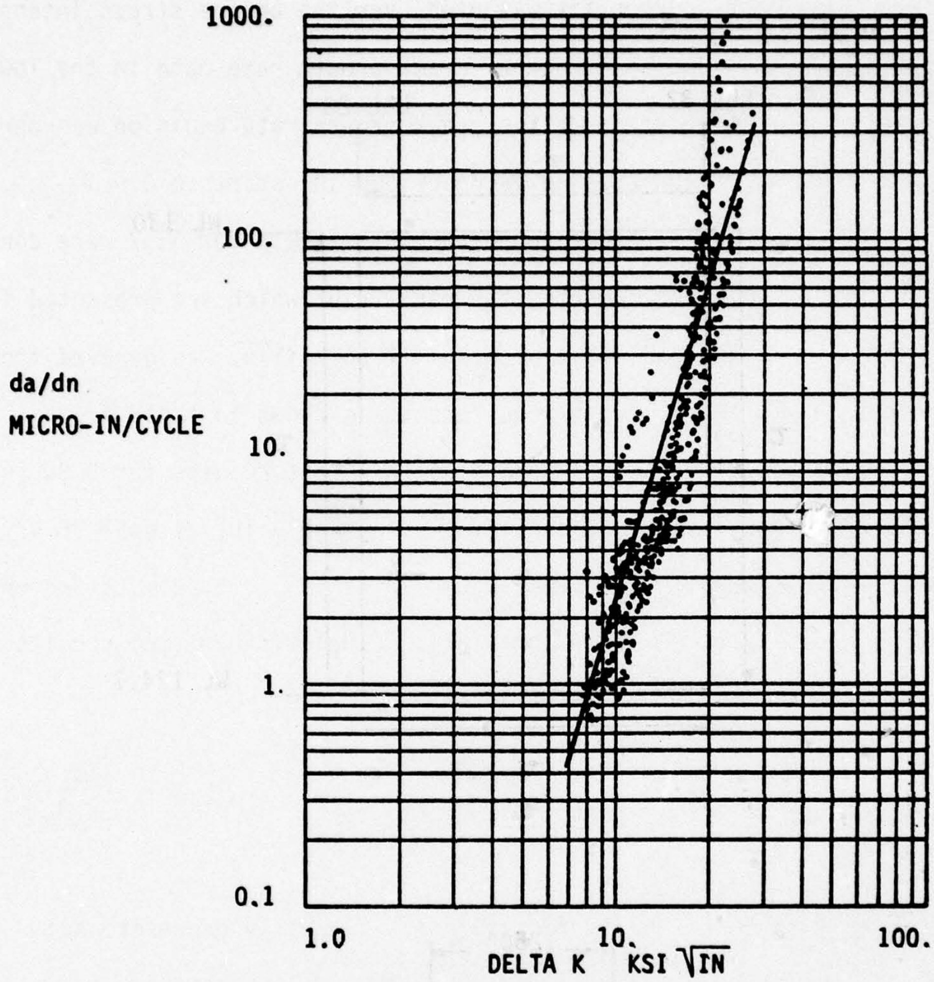


FIGURE 39. SHEAR WEB INITIAL FLAW LOCATION



A357 CRACK GROWTH RATE DATA

TEST GROUP A

R = 0.06, LAB AIR

AVERAGE CRACK GROWTH RATE

$$\frac{da}{dn} = (4.76 \times 10^{-11})(1-R)^{3.70}(K_{max})^{4.70}$$

FIGURE 40. A357 ALUMINUM CRACK GROWTH RATE DATA

This least-squares fit was used over the entire stress intensity range (i.e., $K_{th} = 0$) due to a lack of crack growth rate data in the lower ΔK region. The integration of the crack growth rate equation was performed by computer program POWERS7 and is described in reference 2.

Plane strain fracture toughness (K_{IC}) tests for A357 were conducted per ASTM 399-74 requirements, the results of which are presented in reference 1. An average value of $K_{IC} = 17.55$ ksi$\sqrt{in.}$ was derived from specimens that met K_{IC} validity requirements as shown in table 1.

Plane stress fracture toughness (K_C) test results for 0.20-inch-thick A357 are reported in reference 7. An average value of $K_C = 38.47$ ksi$\sqrt{in.}$ was derived from the specimens shown in table 2. Specimens for which the final crack length exceeded one-third of the width of the specimens were not used in deriving the average value of K_C.

c. Stress Intensity Factor Solution

The stress intensity factor, K, is generally expressed as:

$$K = \sigma \cdot \sqrt{\pi a} \cdot Y$$

The correction factor for radius corner flaws, Y_{CF}, is the result of a number of correction factors found in reference 3 for the case of a corner radius flaw originating at a loaded hole as shown in figure 38.

The applied stress, σ, is the bearing stress resulting from the applied load through the pin and the clevis geometry.

TABLE 1. K_{IC} PLANE STRAIN FRACTURE TOUGHNESS DATA

SPECIMEN IDENTIFICATION	* K_{IC} (KSI $\sqrt{IN.}$)
ACT 3-2	16.6
ACT 4-2	16.0
ACT 7-1	19.4
ACT 8-1	18.2

* Specimens meet ASTM E399-74 validity requirements

$$(K_{IC})_{AVG} = \frac{70.20}{4} = 17.55 \text{ KSI} \sqrt{\text{IN.}}$$

TABLE 2. K_c PLANE STRESS FRACTURE TOUGHNESS DATA

SPECIMEN IDENTIFICATION	K_{APP} (KSI $\sqrt{IN.}$)
ACC 1-1	36.11
ACC 1-2	34.73
ACC 2-1	41.35
ACC 2-2	45.75
ACC 3-2	42.90
ACC 4-1	35.90
ACC 4-2	35.23
ACC 5-1	45.22
ACC 6-2	45.02
ACC 7-1	49.38
ACC 7-2	35.01
ACC 8-1	29.67
ACC 8-2	23.87

$$(Kc)_{AVG} = \frac{500.14}{13} = 38.14 \ \text{KSI}\sqrt{\text{IN.}}$$

The stress intensity solution used for the corner radius flaw at a pin-loaded hole is:

$$K = \sigma \cdot \sqrt{\pi a} \cdot Y_{CF}$$

$$\text{where } Y_{CF} = 1/\sqrt{Q} \cdot M_F \cdot M_B \cdot F_6 \cdot [\cos^2\beta + a^2/c^2 \sin^2\beta]^{1/4}$$

$$\sqrt{\frac{2r + \pi ac/4t}{2r + 2\pi ac/4t}} \qquad \text{(ref. 3)}$$

The correction factor used for the surface flaw case, Y_{SF}, is derived from reference 4.

The surface flaw is oriented such that the principal tensile stresses acting on the web are perpendicular to the crack.

The stress intensity solution used for the surface flaw is:

$$K = \sigma \cdot \sqrt{\pi a} \cdot Y_{SF}$$

$$\text{where } Y_{SF} = 1/\sqrt{Q} \cdot M_B \cdot [\cos^2\beta + a^2/c^2 \sin^2\beta]^{1/4} \qquad \text{(ref. 4)}$$

$$\text{and} \qquad \sigma = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\frac{\sigma_x + \sigma_y}{2} + txy^2}$$

d. Loads

The repeated external loads noted in reference 2 are used for the analyses. The stresses applied are representative of the design usage as given by the mission mix of reference 2. Local stresses for both details were derived from unit load solutions based on finite element analysis of the bulkhead. Analysis stresses for attachment point A and shear web details are presented in appendix A and appendix B, respectively.

MIL-A-83444 requires that the assumed initial damage of in-service noninspectable slow crack growth structure shall not grow to critical size in two design service lifetimes. It also specifies that the structure must be capable of withstanding a residual strength load, P_{LT}, which is the maximum average internal member load that will occur once in 20 lifetimes. The residual strength load to be applied to the bulkhead is the design limit load for the Boeing Side Load condition and is given in reference 5.

e. Results

Damage tolerance analysis results presented in table 3 demonstrate that the requirements specified in MIL-A-83444 for in-service noninspectable slow crack growth structure were met for both details:

AD-A057 422 BOEING AEROSPACE CO SEATTLE WASH F/G 1/3
COST ALUMINUM STRUCTURES TECHNOLOGY, PHASE III (CAST).(U)
JAN 78 D GOEHLER F33615-76-C-3111
UNCLASSIFIED D180-22807-1 AFFDL-TR-78-7 NL

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9-78
DDC

TABLE 3 FLAW GROWTH SUMMARY FOR BULKHEAD DETAILS

DETAIL	$a_{initial}$	$a_{1\ life}$ *	$a_{2\ lives}$ *	$a_{critical}$ **
Load Attachment Point A	0.05"	0.050"	0.050"	0.10"
Shear Web (LBL 28-32/ WL 124.7-130)	0.125"	0.125"	0.125"	4.39"

* One serivce life consists of 1516 applications of the mission mix block

** $a_{critical}$ is determined using design limit load.

- o Outer load attachment point A -- Preliminary analyses reported in reference 6 showed that the initial flaw grew to 0.10 inch in two service lives. This preliminary analysis assumed the attachment point to be loaded in uniform tension. A more realistic pin loading was assumed in the current analysis, resulting in smaller stress intensity factors. In addition, the assumed crack growth rate used for analysis in reference 6 is significantly faster than that derived from test data. The combined effect of smaller K values and slow crack growth rate results in less crack growth than shown in the preliminary analysis (ref. 6). In two service lives, the corner radius flaw assumed at load attachment point A grows from 0.05 inch to 0.05036 inch. Critical crack length for this detail based on P_{LT} = 25.59 ksi and K_{IC} = 17.55 ksi$\sqrt{in.}$ was calculated to be 0.10 inch.
- o Shear web between LBL 28-LBL 32 and WL 124.7-WL 130 -- The surface flaw grows from an initial value of a = 0.125 inch, 2c = 0.250 inch to a = 0.12505 inch, 2c = 0.2501 inch in two service lifetimes. Critical crack length for this detail based on P_{LT} = 10.36 ksi and K_C = 38.47 ksi$\sqrt{in.}$ was found to be 4.39 inches.

A357 fatigue crack growth test results showed that little growth occurred below a stress intensity level of 10 ksi$\sqrt{in.}$ The maximum spectrum stress intensity, K_{max}, in the damage tolerance analysis for the 0.05-inch radius corner flaw at attachment point A is 7.25 ksi$\sqrt{in.}$, while K_{max} for the shear web surface flaw (2c = 0.250 inch, a = 0.125 inch) is 4.55 ksi$\sqrt{in.}$ The maximum stress intensity that occurs each flight in the spectrum for the 0.05-inch radius corner flaw at attachment point A is 2.32 ksi$\sqrt{in.}$, whereas for the shear web the maximum stress intensity that occurs every flight is 1.41 ksi$\sqrt{in.}$ Therefore, little crack growth would be expected for either detail since the spectrum stress intensities for cracks on the order of MIL-A-83444 assumed initial flaw sizes are well below 10 ksi$\sqrt{in.}$

3. SENSITIVITY STUDIES

Sensitivity studies were performed to identify the sensitivity of crack growth life predictions to material properties, aircraft usage, and the initial flaw size assumed to exist. The details used for the studies are those selected for the damage tolerance analysis (sec. III.2, fig. 37):

- o Outer load attachment point A
- o Shear web located between LBL 28-LBL 32 and WL 124.7-WL 130.

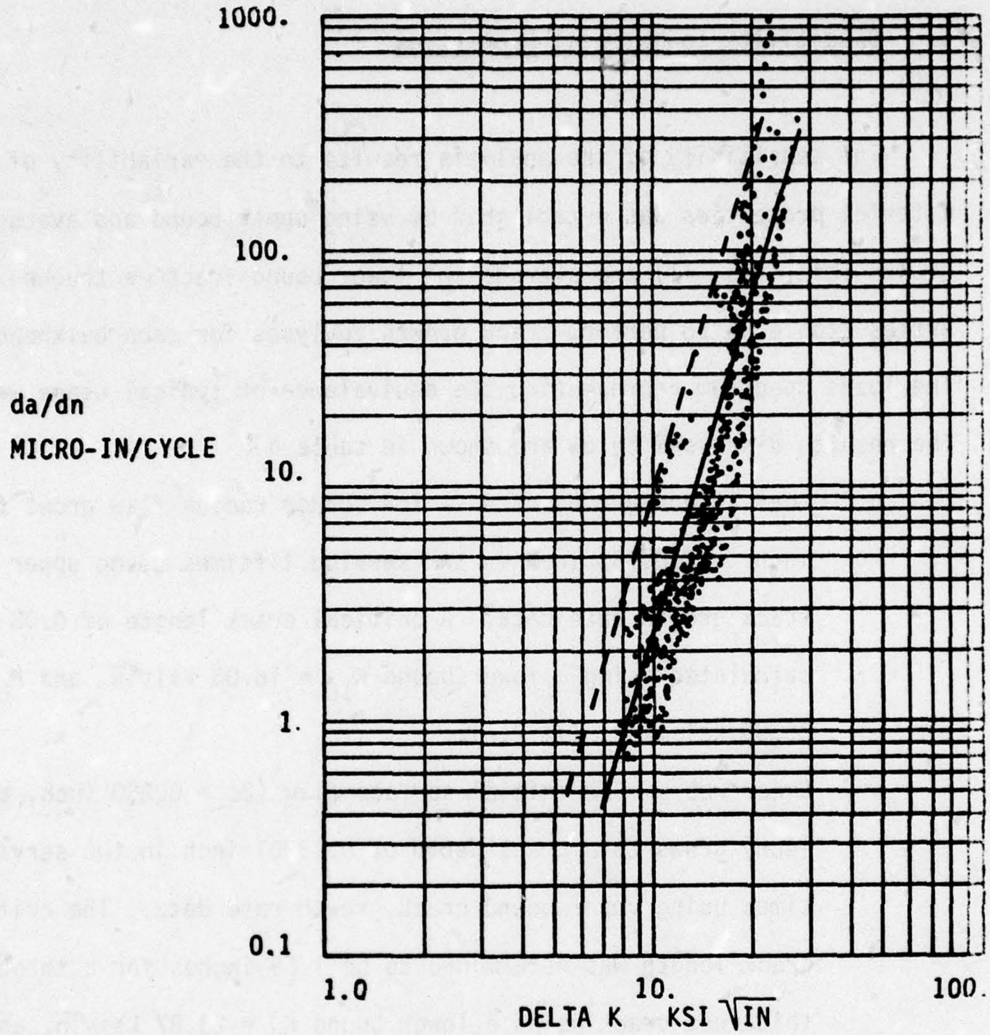
The results of these studies are presented below.

a. Sensitivity to Material Properties

The sensitivity of the analysis results to the variability of the material properties was established by using upper bound and average crack growth rate (fig. 41) and average and lower bound fracture toughness properties (table 4) to perform crack growth analyses for each bulkhead detail. The loads spectrum representing the equivalence of typical usage was used. The results discussed below are shown in table 4.

- o Load attachment point A -- The corner radius flaw grows from 0.05 inch to 0.05933 inch in two service liftimes using upper bound crack growth rate data. A critical crack length of 0.08 inch was calculated using a lower bound K_{IC} = 16.00 ksi$\sqrt{in.}$ and P_{LT} = 25.59 ksi (sec. III.2.e).
- o Shear web -- The initial surface flaw (2c = 0.250 inch, a = 0.125 inch) grows to a crack depth of 0.13201 inch in two service lifetimes using upper bound crack growth rate data. The critical crack length was determined to be 1.69 inches for a through-the-thickness crack using a lower bound K_C = 23.87 ksi$\sqrt{in.}$ and P_{LT} = 10.36 ksi (sec. III.2.e).

The use of upper bound crack growth rate data had little effect on the crack growth results for either detail, while lower bound fracture toughness properties caused the critical crack lengths of the details to be smaller. Thus, MIL-A-83444 requirements can still be met using upper bound crack growth data and lower bound fracture toughness properties.



TEST GROUP A

R = 0.06, LAB AIR

AVERAGE CRACK GROWTH RATE

——— $\frac{da}{dn} = (4.76 \times 10^{-11})(1-R)^{3.70}(K_{max})^{4.70}$

UPPER BOUND CRACK GROWTH RATE

----- $\frac{da}{dn} = (1.53 \times 10^{-10})(1-R)^{3.70}(K_{max})^{4.70}$

FIGURE 41 A357 CRACK GROWTH RATE DATA

TABLE 4. MATERIAL PROPERTIES SENSITIVITY STUDIES

DETAIL	MATERIAL DATA		$a_{initial}$	$a_{1\ life}$	$a_{2\ lives}$	$a_{critical}$
	da/dn*	K_{IC}**				
LOAD ATTACHMENT POINT A	AVERAGE DATA	AVERAGE DATA	0.05"	0.050"	0.050"	0.10"
(CORNER FLAW AT A HOLE)	UPPER BOUND DATA	LOWER BOUND DATA	0.05"	0.050"	0.050"	0.08"
SHEAR WEB (SURFACE FLAW)	AVERAGE DATA	AVERAGE DATA	0.125"	0.125"	0.125"	4.39"
	UPPER BOUND DATA	LOWER BOUND DATA	0.125"	0.125"	0.125"	1.69"

*AVERAGE DATA $C = 4.76 \times 10^{-11}$, $N = 3.70$, $M = 4.70$

UPPER BOUND DATA $C = 1.53 \times 10^{-10}$, $N = 3.70$, $M = 4.70$

**LOAD ATTACHMENT POINT A: (t = 0.09") AVERAGE DATA $K_{IC} = 17.55$ KSI $\sqrt{IN}$

LOWER BOUND DATA $K_{IC} = 16.00$ KSI $\sqrt{IN}$

SHEAR WEB: (t = 0.20") AVERAGE DATA $K_C = 38.47$ KSI $\sqrt{IN}$

LOWER BOUND DATA $K_C = 23.87$ KSI $\sqrt{IN}$

b. Sensitivity to Aircraft Usage

Crack growth analyses were performed for the two bulkhead details using average crack growth data (fig. 41) and fracture toughness properties (sec. III.2.b). Loads spectra representing aircraft usage which is more damaging than typical usage were used for this study. This spectrum consists of a mission mix containing three more STOL flights and three fewer CTOL flights than typical usage as shown in table 5. One service life of typical usage would contain 15,160 CTOL and 9,096 STOL flights, whereas the usage defined in this study contains 10,612 CTOL and 13,644 STOL flights in each lifetime. Typical usage is defined by the loads spectrum in appendix C of reference 2. Studies concerning spectra that are less damaging than normal usage were not conducted due to the small amount of crack growth produced by the typical usage loads spectrum.

The results of the aircraft usage sensitivity studies are presented in table 6. In two design service lifetimes, the radius corner flaw at load attachment point A grew from 0.05 inch to 0.05048 inch, whereas the shear web surface flaw grew from a surface crack length (2c) of 0.250 inch to 0.2512 inch. From these results, it is evident that the change in mission mix for this study had little effect on the crack growth.

c. Sensitivity to Initial Flaw Assumption

Crack growth analyses were performed assuming larger initial flaw sizes than defined in MIL-A-83444. Average material properties (sec. III.2.b and typical aircraft usage were assumed.

TABLE 5 MISSION MIX MAKE-UP

FLIGHT TYPE	TYPICAL USAGE	STUDY USAGE
1 (CTOL)	1	1
2 (CTOL)	4	1
3 (STOL)	3	3
4 (CTOL)	5	5
5 (STOL)	3	6
FLIGHTS / BLOCK	16	16

TABLE 6 *AIRCRAFT USAGE SENSITIVITY STUDIES*

DETAIL	SPECTRUM MAKE-UP	$a_{initial}$	$a_{1\ life}$	$a_{2\ lives}$
LOAD ATTACHMENT POINT A (CORNER FLAW AT A HOLE)	TYPICAL USAGE	0.05"	0.050"	0.050"
	STUDY USAGE	0.05"	0.050"	0.050"
SHEAR WEB (SURFACE FLAW)	TYPICAL USAGE	0.125"	0.125"	0.125"
	STUDY USAGE	0.125"	0.125 "	0.125 "

The results of this study are presented in table 7. An initial corner radius flaw of 0.06 inch was assumed for outer load attachment point A. This grew to a flaw size of 0.06051 inch in two service lives. Additionally, when an initial flaw size of 0.080 inch was assumed, the crack grew to 0.090 inch in two service lifetimes, still below the 0.10-inch critical crack length. The shear web surface flaw was assumed to begin at a depth (a) of 0.150 inch and a surface length (2c) of 0.300 inch. After two service lifetimes of typical aircraft usage, the crack grew to a depth of 0.15008 inch and a surface length of 0.30016 inch. Analysis assuming an initial through-the-thickness flaw length of 1.35 inches resulted in the crack growing to a length of 3.00 inches in two lives.

From these analyses, it is evident that an equivalent initial flaw size that is much larger than that required by MIL-A-83444 will not grow to critical crack size in two service lifetimes for either detail.

4. DURABILITY ANALYSIS

Durability analyses were performed for the details selected for the damage tolerance analysis:

- Outer load attachment point A
- Shear web located between LBL 28-LBL 32 and WL 124.7-WL 130

Detail locations are presented in figure 37. The loads acting on these two details were calculated from external loads using unit load solutions derived from finite element analysis results. The Boeing Durability Method is used for all durability calculations (ref. 2).

TABLE 7. INITIAL FLAW ASSUMPTION SENSITIVITY STUDIES

DETAIL	a initial	a 1 life	a 2 lives
LOAD ATTACHMENT POINT A (CORNER FLAW AT A HOLE)	0.05"	0.050"	0.050"
	0.06"	0.060"	0.060"
	0.080"	0.083"	0.090"
SHEAR WEB (SURFACE FLAW)	0.125"	0.125"	0.125"
	0.150"	0.150"	0.150"
	1.350"	1.985"	3.00"

a. Detail Design S-N Curves

The S-N curves for A357 are developed from fatigue test data for both smooth and open-hole fatigue test specimens as shown in figure 42. The design S-n curves for each detail are derived from test data by applying appropriate factors to achieve 95% confidence and 95% reliability. Detail design S-N curves for smooth and open-hole specimens are presented in figures 43 and 44, respectively.

Detail design S-N curves are expressed by two parameters: a detail fatigue rating, DFR, and slope ratio, S. The slope ratio, S, is generally constant at 2.0 for aluminum alloys. The geometric severity of a particular detail considering its fatigue performance is therefore expressed by the DFR.

For a clevis or lug detail, the DFR is derived from:

$$DFR = DFR_{BASE} \cdot A \cdot L_s \cdot L_d \cdot L$$

The DFR_{BASE} value accounts for the particular geometry of the clevis or lug. Since the DFR_{BASE} charts are presently derived for wrought aluminum alloys, the factor A accounts for the effect of the casting alloy. The factor A is derived as the ratio:

$$A = \frac{\text{DFR (OPEN HOLE A357)}}{\text{DFR (OPEN HOLE 2024)}}$$

where DFR (open hole A357) is as shown on figure 44 and DFR (open hole 2024) is obtained from durability design charts.

Therefore,

$$A = \frac{11.0}{16.5} = 0.67$$

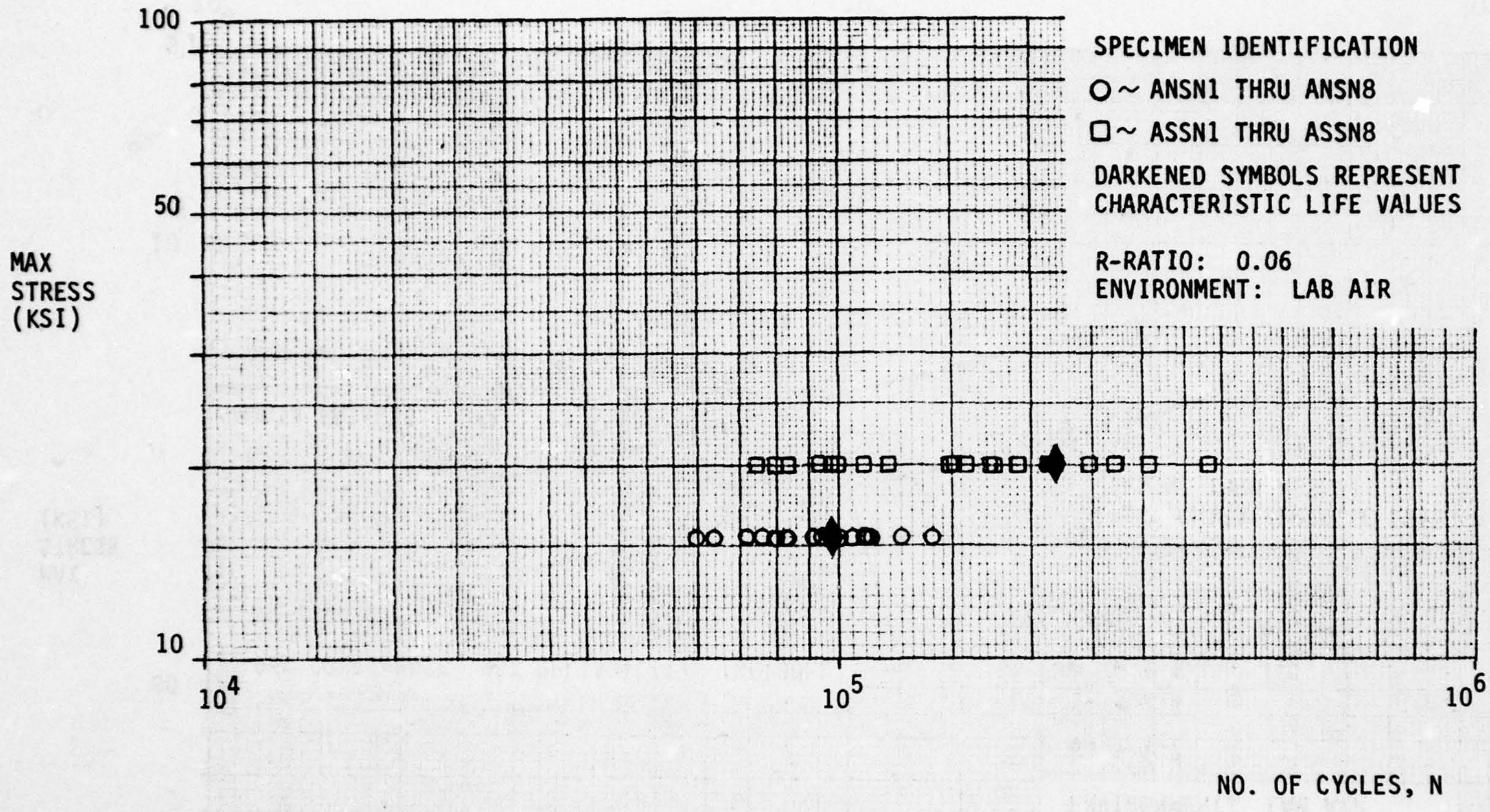


FIGURE 42. A357 S-N DATA FOR SMOOTH AND OPEN HOLE SPECIMENS

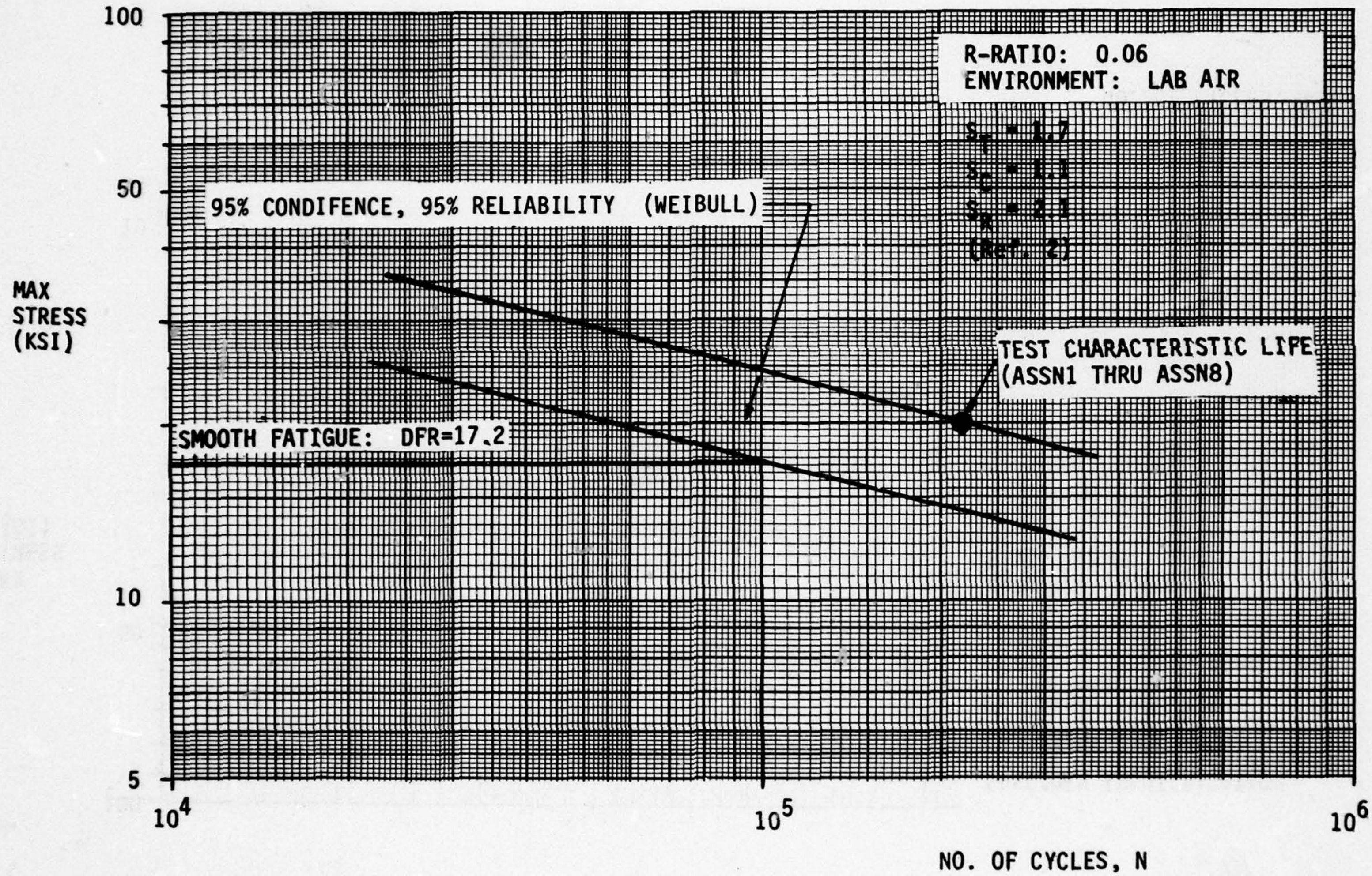


FIGURE 43. DETAIL DESIGN S-N CURVES FOR SMOOTH FATIGUE SPECIMENS

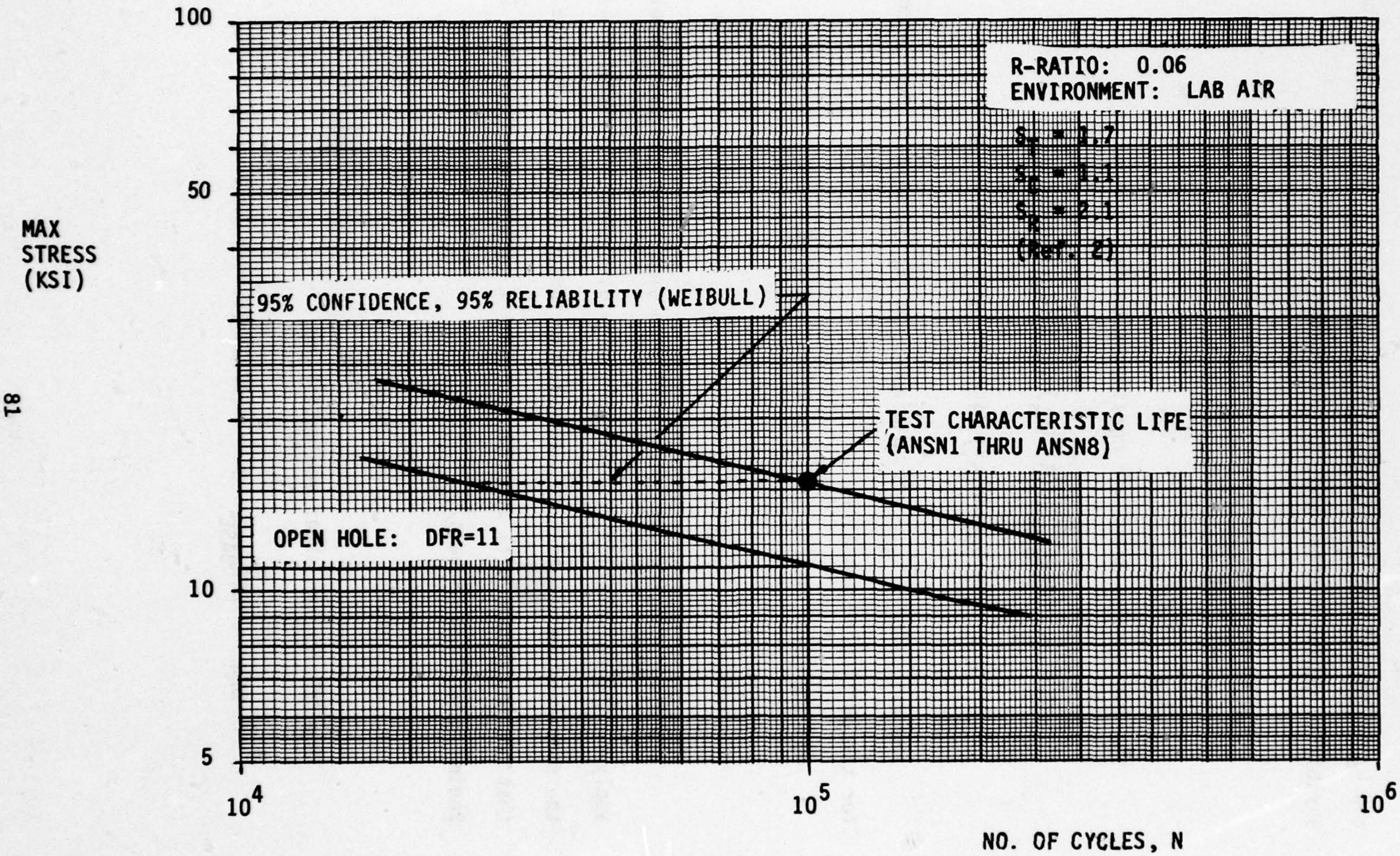


FIGURE 44. DETAIL DESIGN S-N CURVES FOR OPEN HOLE SPECIMENS

L_s and L_d represent the geometric size and shape factor, respectively, and L_θ is the oblique load factor. L_s, L_d, and L_θ are obtained from the durability design charts, and for this case:

$$L_s = 1.00$$

$$L_d = 1.06$$

$$L_\theta = 1.00$$

The DFR for the detail in consideration is

$$DFR = (DFR_{BASE})\ (A)\ (L_s)\ (L_d)\ (L_\theta)$$

$$= (12.80)\ (0.67)\ (1.0)\ (1.06)\ (1.0) = 9.1$$

The value for DFR_{BASE} is obtained from the durability design charts for the particular geometry.

For the shear web detail, the DFR is derived from:

$$DFR = DFR_{BASE} \cdot B$$

The DFR_{BASE} value was calculated from smooth fatigue test results applying the reliability considerations as discussed in reference 2. Since the specimens were loaded in tension, the factor B accounts for the fact that the web detail will be loaded in shear. The factor B is from the Boeing Durability Manual:

$$B = 0.7$$

The DFR for the shear web detail is:

$$DFR = DFR_{BASE} \cdot B = (17.2)\ (0.7) = 12.0$$

b. Economic Life

The economic life of the cast bulkhead is predicted for the design usage as represented by the mission mix noted in reference 2. The relative damage due to the five different flights within the mission mix consisting of 16 total flights is calculated and summarized for both the load attachment point A and shear web details in tables 8 and 9, respectively.

The relative damage of each flight is the sum of the damages of the individual stress excursions applied during each flight. The relative damages for the individual stress cycles are calculated from the S-N curves by:

$$\text{relative damage} = \frac{100{,}000}{N_{S-N}} \cdot n_{applied}$$

The GAG damage ratio is calculated from

$$\text{GAG damage ratio} = \frac{\text{relative damage GAG cycle}}{\text{relative damage total flight}}$$

For load attachment point A, the average GAG cycle was determined to be:

$$(f_{max})_{GAG} = 7.88 \text{ ksi}$$

$$(f_{min})_{GAG} = 0.0 \text{ ksi}$$

The average relative damage of this GAG cycle is established as:

relative GAG damage = 0.361 (ref. table 8)

The average GAG damage ratio for this detail is:

0.361/1.242 = 0.29

TABLE 8. LOAD ATTACHMENT POINT A--RELATIVE DAMAGE

FLIGHT TYPE	No. of FLIGHTS	DAMAGE EACH FLIGHT [1]	TOTAL DAMAGE	GAG DAMAGE EACH FLIGHT
1	1	1.055	1.055	0.542
2	4	1.055	4.220	0.542
3	3	1.424	4.272	0.279
4	5	0.629	3.145	0.279
5	3	2.394	7.182	0.279
	16		19.874	
average damage per flight = 1.242				
average GAG damage = 0.361				

[1] based on DFR = 16

TABLE 9. SHEAR WEB--RELATIVE DAMAGE

FLIGHT TYPE	NO. OF FLIGHTS	DAMAGE EACH FLIGHT [1]	TOTAL DAMAGE	GAG DAMAGE EACH FLIGHT
1	1	0.0227	0.0227	0.0178
2	4	0.0227	0.0908	0.0178
3	3	0.0414	0.1242	0.0281
4	5	0.0164	0.0820	0.0123
5	3	0.0526	0.1578	0.0281
	16		0.04775	
average damage per flight = 0.0298				
average GAG damage = 0.0220				

[1] based on DFR = 16

For the life predictions, the GAG cycle will be used in place of the variable amplitude flight stress excursions. For that purpose, an equivalent number of cycles for the GAG excursions must be established as the life goal. The design service life of the bulkhead is 25,000 hours. Using the average duration for one flight of 1.03 hours, the number of flights is 24,272. The equivalent number of GAG cycles for the life requirement is:

$$N_{equ} = \frac{(N_{FLIGHTS})\ (FRF)}{\text{GAG damage ratio}}$$

$$N_{equ} = \frac{(24272)\ (1.5)}{0.2907} = 125{,}243 \text{ cycles}$$

An additional fatigue reliability factor, FRF, is applied in accordance with the Boeing Durability Method. The factor is mainly a function of the location of the analysis detail on the airplane.

Using the detail design curve defined by a DFR = 9.1, f_{max} = 7.88 ksi, and R = 0 for the clevis detail results in a life prediction expressed in terms of GAG cycles of 135,000 cycles. In terms of hours, the economic life is predicted as:

$$\text{life} = (25000)\ \frac{(135{,}000)}{(125{,}243)} = 26{,}948 \text{ hours}$$

The economic life therefore exceeds the design life by 8%. In terms of stresses, the fatigue margin is:

$$FM = \frac{F_{max}}{f_{max}} - 1 = \frac{8.25}{7.88} - 1 = 0.037$$

where F_{max} is the maximum allowable GAG stress.

The shear web analysis was performed in the same manner. The GAG cycle was determined to be:

$$(f_{max})_{GAG} = 2.85 \text{ ksi}$$

$$(f_{min})_{GAG} = -3.16 \text{ ksi}$$

The average relative damage for this GAG cycle as shown in table 9 is:

$$\text{relative GAG damage} = 0.0200$$

The average GAG damage ratio for this detail is:

$$\frac{0.0200}{0.0298} = 0.67$$

The equivalent number of GAG cycles for the life requirement becomes:

$$N_{equ} = \frac{(24272)\ (1.5)}{(0.67)} = 54{,}340 \text{ cycles}$$

Using the detail design curve defined by a DFR = 12.0, f_{max} = 2.85 ksi, and R = -0.9 for the shear web detail results in a life prediction that is very large. The economic life therefore exceeds the design life by a large margin.

5. WEIGHTS

The calculated weight of the bulkhead casting is 205.2 lb. This weight results from a detailed weight calculation of the bulkhead and includes a +2.5% increment for manufacturing tolerance. The 2.5% represents half the drawing tolerance over nominal (+0.005) on web and flange thickness. Past experience with aircraft parts calculated at nominal dimensions versus actual part weight shows this approach to be satisfactory. The density value of A357 cast aluminum was assumed to be the same as for A356, which is 0.097 lb/in.^{3}.

The weight of the finished machined bulkhead including bushings is 181.1 lb. This weight results from machining the periphery to contour and machining the interfaces for the nose gear and door actuator fittings.

The finished bulkhead weight of 181.1 lb results in a 6.5-lb weight reduction when compared to the updated baseline component weight of 187.6 lb.

6. COST

The cost summary for the YC-14 station 170 cast bulkhead is shown in figure 45. These cost figures are based on the CAST bulkhead assembly, 162-00018, using the final detail design of the station 170 bulkhead casting, 162-00017, as the major part.

	No. 1 A/P cost	300 A/P cost
Raw material	$ 1,870	$ 309,000
Labor:		
Detail and assembly tools	200,018	200,018
Foundry tools	95,000	95,000
Fabrication	10,003	1,482,313
Section installation	– –	247,680
Total	$306,891	$2,334,011
Cost per unit	$306,891	$ 7,780

Figure 45. Station 170 Cast Bulkhead Costs

The raw material figure covers aluminum, sand, and binder. The aluminum, for one unit only, comes to almost 2000 lb including the bulkhead and all excess material, i.e., gates, risers, flashing, etc. For the 300-unit production run, approximately 75% of each pour is remelted and brought up to specification requirements for the next pour with completely new material used after each five castings. The sand and binder are not reusable.

The item for detail and assembly tools covers the initial hard production tooling costs only. The figure shown for the No. 1 airplane would be drastically reduced if only one unit were to be made.

The foundry tool costs cover the pattern, special mold flask tooling, and chills.

Fabrication costs for the 300-unit production run include a factored cost increment for tool maintenance and refurbishment.

The section installation costs shown are the same as shown on the updated baseline component. These costs were not recalculated based on the assumption that final installation cost differences between a built-up and a cast bulkhead would be negligible.

Engineering costs are not included here, nor are they included in the updated baseline costs in section II.5.b. For a 300-unit production run, the unit cost for engineering is relatively small, having little or no effect on the cost comparison between a built-up and a cast bulkhead.

The cost comparison between the updated baseline component as noted in section II.5.b and the detail designed cast bulkhead (fig. 45) is as shown:

$$\Delta\text{Cost} = \frac{12484 - 7780}{12484}(100) = 37.7\% \text{ reduction}$$

7. EFFECT OF DEFECTS

The occurrence of discontinuities in the castings produced during the development of foundry manufacturing procedures did not result in a wide variety of discontinuity types or sizes from which to test the effects of defects. Also, few defects were found in locations having sufficient material for specimen fabrication. The most common discontinuities encountered were gas and shrink porosity, sponge and shrinkage cavities, and less dense inclusions. Crack-like discontinuities were almost completely absent.

With a given casting, some discontinuities, such as shrinkage cavities and sponge, can be anticipated in certain locations because of an association with mold design, gating, risering, chilling, and other foundry practices. However, experience in Phase II has shown that many of the common discontinuities (dross, inclusions, and gas pores) have occurred randomly. Dispersed shrinkage porosity was somewhat controlled by type and placement of chills, but the presence of this condition away from chills was unpredictable.

The capability of NDE (nondestructive evaluation) to detect "defects" is difficult to assess quantitatively. Results of both the penetrant method for surface discontinuities and radiography for those occurring internally are highly subjective in interpretation. Industry reference standards and defect dimensional limits for penetration inspection do not exist. Reference radiographs under ASTM E155 are only comparative standards and no means of quantifying many of the defect conditions seems presently feasible. Therefore, in reality, inspectors exercise considerable individual judgement in evaluating those discontinuities that are tolerable in some approximate degree.

NDE capabilities are also significantly influenced by many manufacturing process and inspection technique variables. While it was shown that penetrant methods will reveal pore openings of the order of 0.001-inch diameter in cast surfaces, sawing, grinding, and abrasive blasting will prevent detection of these and much larger openings. Larger shallow defects also may be overlooked if technique is not closely controlled. Radiographic technique is often governed by configuration of the casting. Individual pores of 0.002-0.003 inch may be detected in 0.125-inch-thick material, but must be of the order of 0.015-inch diameter to be resolved through 0.75-inch-thick material. Also, crack-like defects must be oriented closely parallel to the incident X-ray beam to be detected in any thickness.

Because of the importance of human, processing, and technique factors, precise quantitative determination of NDE capabilities must be based on a statistical approach. Such a study is outside of the scope of this program. However, determination of what types and levels of discontinuities are truly "defects" is of initial importance. Considerable information is expected from the allowables and effects of defects data, in conjunction with fractographic examination and correlation with NDE results. When complete, this will provide some measure of actually achieved NDE capabilities, and aid in determining necessary NDE improvements and final requirements.

Improvement in NDE is needed in the following areas:

1. Assuring soundness of heavy sections, greater than 0.75-inch thickness.
2. Penetrant standards for porosity-type discontinuities.

The analytical approach to the effects of defects consists of accounting for defects in crack growth and fatigue analysis by using the equivalent initial flaws and detail fatigue ratings (DFR) for the various types of defects and X-ray grades.

The equivalent flaws and DFR's are being derived from constant-amplitude fatigue specimen tests. Specimens have been saw cut from existing castings considering the defect types and X-ray grades as presented in table 10. The specimens were located on the existing castings (20- x 40-inch fracture toughness panels and Hitchcock #9 casting) such that the defects are placed approximately in the center of the test section.

In order to evaluate specimen size effect, a number of 6- x 12-inch specimens in addition to the regular S-N specimens will be tested. The experiments will yield cycles to failure, from which equivalent initial flaws will be derived by calculating the initial dimensions of an assumed flaw that results in a crack growth life equal to the test life. DFR's will be determined from the cycles to failure according to the procedure described in appendix E of reference 2.

TABLE 10. EQUIVALENT INITIAL FLAW SIZES FOR TYPES OF DEFECTS AND X-RAY GRADES

<table>
<tr><th rowspan="2">DEFECT TYPE</th><th colspan="3">X-RAY GRADES</th></tr>
<tr><th>B</th><th>C</th><th>D</th></tr>
<tr><td>GAS HOLES</td><td colspan="3" rowspan="6">Equivalent Initial Flaw Sizes to be Determined from Experiments</td></tr>
<tr><td>GAS POROSITY (ROUND)</td></tr>
<tr><td>GAS POROSITY (ELONGATED)</td></tr>
<tr><td>SHRINKAGE CAVITY</td></tr>
<tr><td>SHIRNKAGE POROSITY</td></tr>
<tr><td>FOREIGN MATERIAL</td></tr>
</table>

REFERENCES

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2. "Damage Tolerance and Durability Control Plan," January 1977.
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APPENDIX A

LOAD ATTACHMENT POINT A ANALYSIS STRESS SPECTRUM

FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF FLIGHT TYPE NO. 1 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF

FLIGHT TYPE = FLIGHT TYPE 1
NUMBER OF FLIGHTS IN THE BLOCK = 1
PCT. TOTAL BLOCK DAMAGE THIS FLIGHT CAUSES: UNRET.= 4.14
RET.= 4.33
DURABILITY= 5.32
NUMBER OF SPECTRUM INPUTS DESCRIBING FLIGHT TYPE = 41

LABEL	FMAX	FMIN	CYCLES	RET.FAC.	PERCENT OF UA PER FLIGHT UNRETARDED	PERCENT OF UA PER FLIGHT RETARDED	PERCENT DURABILITY
T1	.98	.89	3.000E+02	.000	.00	.00	.00
T2	1.08	.80	1.650E+02	.000	.00	.00	.05
T3	1.17	.70	2.700E+01	.000	.00	.00	.05
T4	1.26	.60	2.000E+00	.000	.00	.00	.01
T5	1.36	.52	9.000E-02	.000	.00	.00	.00
T6	1.45	.42	4.000E-03	.000	.00	.00	.00
L11	1.67	.00	3.120E-01	.000	.01	.00	.04
L11	2.24	.00	3.120E-01	.000	.02	.00	.10
L12	5.72	.00	7.900E-02	.033	.47	.02	.08
L13	3.84	.00	7.900E-02	.000	.07	.00	.17
L21	1.87	.00	1.740E-01	.000	.01	.00	.03
L21	2.53	.00	1.740E-01	.000	.02	.00	.09
L22	6.43	.00	4.300E-02	.134	.45	.07	.56
L23	4.32	.00	4.300E-02	.000	.07	.00	.14
L31	2.50	.00	1.030E-01	.000	.01	.00	.05
L31	3.36	.00	1.030E-01	.000	.05	.00	.14
L32	8.58	.00	2.600E-02	.653	1.04	1.02	.96
L33	5.76	.00	2.600E-02	.037	.16	.01	.23
L41	3.12	.00	5.200E-02	.000	.02	.00	.05
L41	4.21	.00	5.200E-02	.000	.07	.00	.15
L42	10.72	.00	1.300E-02	1.000	1.49	1.70	1.10
L43	7.20	.00	1.300E-02	.326	.23	.09	.25
L51	3.75	.00	1.800E-02	.000	.01	.00	.04
L51	5.03	.00	1.800E-02	.002	.06	.00	.10
L52	12.07	.00	4.000E-03	1.000	1.08	1.23	.88
L53	8.65	.00	4.000E-03	.884	.17	.17	.15
L61	4.37	.00	6.000E-03	.000	.01	.00	.02
L61	5.89	.00	6.000E-03	.052	.04	.00	.06
L62	15.00	.00	1.000E-03	1.000	.56	.63	.31
L63	10.09	.00	1.000E-03	1.000	.09	.10	.07
L71	5.00	.00	2.000E-03	.001	.01	.00	.01
L71	6.72	.00	1.000E-03	.196	.01	.00	.02
L81	5.62	.00	1.000E-03	.024	.01	.00	.01
L81	7.57	.00	1.000E-03	.446	.02	.01	.02
R1	1.00	.94	5.000E+00	.000	.00	.00	.03
R2	4.78	.03	1.000E+00	.000	2.57	.00	4.56
R2	2.27	.94	2.000E+00	.000	.02	.00	.12
SL1	4.78	.03	1.000E+00	.000	2.57	.00	4.56
TL1	8.90	.94	1.000E+00	1.000	31.58	35.99	30.41
TR1	7.03	.94	1.000E+00	.433	9.26	4.57	11.57
GAG	8.90	.00	1.000E+00	1.000	47.73	54.40	42.39

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PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP FLIGHT TYPE NO. 2 PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP

FLIGHT TYPE = FLIGHT TYPE 2
NUMBER OF FLIGHTS IN THE BLOCK = 4
PCT. TOTAL BLOCK DAMAGE THIS FLIGHT CAUSES: UNRET.= 16.57
RET.= 17.33
DURABILITY= 21.29
NUMBER OF SPECTRUM INPUTS DESCRIBING FLIGHT TYPE = 41

LABEL	FMAX	FMIN	CYCLES	RET.FAC.	PERCENT OF UA PER FLIGHT UNRETARDED	PERCENT OF UA PER FLIGHT RETARDED	PERCENT DURABILITY
T1	.98	.89	3.000E+02	.000	.00	.00	.00
T2	1.08	.80	1.650E+02	.000	.00	.00	.05
T3	1.17	.70	2.700E+01	.000	.00	.00	.05
T4	1.26	.60	2.000E+00	.000	.00	.00	.01
T5	1.36	.52	9.000E-02	.000	.00	.00	.00
T6	1.45	.42	4.000E-03	.000	.00	.00	.00
L11	1.07	.00	3.120E-01	.000	.01	.00	.04
L11	2.24	.00	3.120E-01	.000	.02	.00	.10
L12	5.72	.00	7.900E-02	.033	.47	.02	.08
L13	3.84	.00	7.900E-02	.000	.07	.00	.17
L21	1.07	.00	1.740E-01	.000	.01	.00	.03
L21	2.53	.00	1.740E-01	.000	.02	.00	.09
L22	6.43	.00	4.300E-02	.134	.45	.07	.56
L23	4.32	.00	4.300E-02	.000	.07	.00	.14
L31	2.50	.00	1.030E-01	.000	.01	.00	.05
L31	3.36	.00	1.030E-01	.000	.05	.00	.14
L32	8.58	.00	2.600E-02	.853	1.04	1.02	.96
L33	5.76	.00	2.600E-02	.037	.16	.01	.23
L41	3.12	.00	5.200E-02	.000	.02	.00	.05
L41	4.21	.00	5.200E-02	.000	.07	.00	.15
L42	10.72	.00	1.300E-02	1.000	1.49	1.70	1.10
L43	7.20	.00	1.300E-02	.326	.23	.09	.25
L51	3.75	.00	1.800E-02	.000	.01	.00	.04
L51	5.03	.00	1.800E-02	.002	.06	.00	.10
L52	12.87	.00	4.000E-03	1.000	1.08	1.23	.08
L53	8.05	.00	4.000E-03	.684	.17	.17	.15
L61	4.37	.00	6.000E-03	.000	.01	.00	.02
L61	5.89	.00	6.000E-03	.052	.04	.00	.06
L62	15.00	.00	1.000E-03	1.000	.56	.63	.31
L63	10.09	.00	1.000E-03	1.000	.09	.10	.07
L71	5.00	.00	2.000E-03	.001	.01	.00	.01
L71	6.72	.00	1.000E-03	.196	.01	.00	.02
L81	5.02	.00	1.000E-03	.024	.01	.00	.01
L81	7.57	.00	1.000E-03	.446	.02	.01	.02
R1	1.00	.94	5.000E+00	.000	.00	.00	.03
R2	2.27	.94	2.000E+00	.000	.02	.00	.12
SL1	4.78	.00	1.000E+00	.000	2.57	.00	4.56
R7	4.78	.00	1.000E+00	.000	2.57	.00	4.56
TL1	8.90	.94	1.000E+00	1.000	31.58	35.94	30.41
GAG	8.90	.00	1.000E+00	1.000	47.73	54.40	42.39
TH1	7.03	.94	1.000E+00	.433	4.26	4.57	11.57

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PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP FLIGHT TYPE NO. 3 PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP

FLIGHT TYPE = FLIGHT TYPE 3
NUMBER OF FLIGHTS IN THE BLOCK = 3
PCT. TOTAL BLOCK DAMAGE THIS FLIGHT CAUSES: UNRET.= 24.41
RET.= 24.77
DURABILITY= 21.59
NUMBER OF SPECTRUM INPUTS DESCRIBING FLIGHT TYPE = 65

LABEL	FMAX	FMIN	CYCLES	RET.FAC.	PERCENT OF DA PER FLIGHT UNRETARDED	RETARDED	PERCENT DURABILITY
T1	.82	.74	6.000E+02	.000	.00	.00	.00
T2	.90	.66	3.500E+02	.000	.00	.00	.05
T3	.20	.12	5.400E+01	.000	.00	.00	.00
T4	.22	.10	4.000E+00	.000	.00	.00	.00
T5	.23	.09	1.800E-01	.000	.00	.00	.00
T6	.25	.07	8.000E-03	.000	.00	.00	.00
L11	1.39	.00	1.500E-02	.000	.00	.00	.00
L11	1.87	.00	1.500E-02	.000	.00	.00	.00
L12	4.76	.00	4.000E-03	.000	.01	.00	.01
L13	3.20	.00	4.000E-03	.000	.00	.00	.00
L21	1.87	.00	4.500E-02	.000	.00	.00	.01
L21	2.53	.00	4.500E-02	.000	.00	.00	.02
L22	6.43	.00	1.100E-02	.134	.06	.01	.11
L23	4.32	.00	1.100E-02	.000	.01	.00	.03
L31	2.50	.00	9.800E-02	.000	.01	.00	.08
L31	3.36	.00	9.800E-02	.000	.02	.00	.10
L32	8.58	.00	2.500E-02	.853	.51	.51	.88
L33	5.76	.00	2.500E-02	.037	.08	.00	.16
L41	3.12	.00	1.150E-01	.000	.02	.00	.09
L41	4.21	.00	1.150E-01	.000	.08	.00	.25
L42	10.72	.00	2.800E-02	1.000	1.63	1.92	1.76
L43	7.20	.00	2.800E-02	.326	.25	.10	.41
L51	3.75	.00	1.120E-01	.000	.05	.00	.16
L51	5.03	.00	1.120E-01	.002	.19	.00	.45
L52	12.87	.00	2.800E-02	1.000	3.85	4.52	3.53
L53	8.65	.00	2.800E-02	.864	.60	.62	.79
L61	4.37	.00	1.070E-01	.000	.09	.00	.26
L61	5.89	.00	1.070E-01	.052	.37	.02	.75
L62	15.00	.00	2.600E-02	1.000	7.35	8.63	5.99
L63	10.09	.00	2.600E-02	1.000	1.14	1.34	1.30
L71	5.00	.00	7.100E-02	.001	.11	.00	.28
L71	6.72	.00	7.100E-02	.196	.46	.11	.80
L72	17.15	.00	1.800E-02	1.000	9.55	11.21	7.12
L73	11.53	.00	1.800E-02	1.000	1.48	1.73	1.49
L81	5.62	.00	4.600E-02	.024	.13	.00	.27
L81	7.57	.00	4.600E-02	.446	.52	.27	.80
L82	19.30	.00	1.100E-02	1.000	10.17	11.94	7.12
L83	12.97	.00	1.100E-02	1.000	1.57	1.84	1.43
L91	6.16	.00	2.800E-02	.091	.12	.01	.23
L91	8.31	.00	2.800E-02	.734	.49	.43	.68
L92	21.20	.00	7.000E-03	1.000	10.06	11.81	6.77
L93	14.25	.00	7.000E-03	1.000	1.55	1.83	1.31
L101	6.87	.00	1.500E-02	.233	.11	.03	.18
L101	9.24	.00	1.500E-02	1.000	.43	.51	.50
L102	23.59	.00	4.000E-03	1.000	9.50	11.15	6.21
L103	15.85	.00	4.000E-03	1.000	1.47	1.72	1.15
L111	7.50	.00	9.000E-03	.422	.10	.05	.18
L111	10.08	.00	9.000E-03	1.000	.39	.46	.48
L112	25.73	.00	2.000E-03	1.000	7.10	8.38	4.82
L113	17.29	.00	2.000E-03	1.000	1.10	1.29	.82
L121	8.12	.00	5.000E-03	.655	.08	.06	.11
L121	10.92	.00	5.000E-03	1.000	.32	.37	.38
L122	27.87	.00	1.000E-03	1.000	5.20	6.10	3.37
L123	18.73	.00	1.000E-03	1.000	.80	.94	.57
L131	8.82	.00	3.000E-03	.962	.07	.08	.09
L131	11.79	.00	3.000E-03	1.000	.27	.32	.27
L141	9.37	.00	1.000E-03	1.000	.03	.04	.08
L141	12.60	.00	1.000E-03	1.000	.12	.15	.12
R1	1.54	.78	5.000E+00	.000	.00	.00	.03
R2	1.91	.78	2.000E+00	.000	.01	.00	.05
SL1	3.98	.00	1.000E+00	.000	.55	.00	1.70
R2	3.98	.00	1.000E+00	.000	.55	.00	1.70
TL1	7.42	.78	1.000E+00	.561	6.86	4.92	11.51
TR1	5.66	.78	1.000E+00	.076	2.01	.18	4.44
GAG	7.42	.00	1.000E+00	.385	10.34	4.80	16.13

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PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP FLIGHT TYPE NO. 6 PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP

FLIGHT TYPE = FLIGHT TYPE 6
NUMBER OF FLIGHTS IN THE BLOCK = 5
PCT. TOTAL BLOCK DAMAGE THIS FLIGHT CAUSES: UNRET.= 10.72
RET.= 6.09
DURABILITY= 15.95
NUMBER OF SPECTRUM INPUTS DESCRIBING FLIGHT TYPE = 41

LABEL	FMAX	FMIN	CYCLES	RET.FAC.	PERCENT OF DA PER FLIGHT UNRETARDED	PERCENT OF DA PER FLIGHT RETARDED	PERCENT DURABILITY
T1	.82	.70	3.000E+02	.000	.00	.00	.00
T2	.90	.66	1.050E+02	.000	.00	.00	.05
T3	.98	.59	2.700E+01	.000	.00	.00	.04
T4	1.05	.51	2.000E+00	.000	.00	.00	.01
T5	1.13	.43	9.000E-02	.000	.00	.00	.00
T6	1.21	.35	4.000E-03	.000	.00	.00	.00
L11	1.39	.00	6.240E-01	.000	.01	.00	.07
L11	1.87	.00	6.240E-01	.000	.04	.00	.19
L12	4.76	.00	1.580E-01	.000	.77	.00	1.10
L13	3.20	.00	1.580E-01	.000	.12	.00	.30
L21	1.87	.00	3.480E-01	.000	.02	.00	.10
L21	2.53	.00	3.480E-01	.000	.09	.00	.29
L22	6.43	.00	8.600E-02	.134	1.72	.48	1.07
L23	8.32	.00	8.600E-02	.000	.27	.00	.66
L31	2.50	.00	2.060E-01	.000	.05	.00	.17
L31	3.36	.00	2.060E-01	.000	.20	.00	.46
L32	8.50	.00	5.200E-02	.653	4.04	7.22	3.21
L33	5.76	.00	5.200E-02	.037	.62	.05	.76
L41	3.12	.00	1.040E-01	.000	.07	.00	.18
L41	4.21	.00	1.040E-01	.000	.28	.00	.51
L42	10.72	.00	2.600E-02	1.000	5.75	12.05	3.08
L43	7.20	.00	2.600E-02	.326	.69	.60	.85
L51	3.75	.00	3.600E-02	.000	.06	.00	.12
L51	5.03	.00	3.600E-02	.002	.23	.00	.33
L52	12.07	.00	8.000E-03	1.000	4.18	8.75	2.28
L53	8.05	.00	8.000E-03	.084	.65	1.20	.51
L61	4.37	.00	1.200E-02	.000	.04	.00	.07
L61	5.09	.00	1.200E-02	.052	.16	.02	.19
L62	15.00	.00	2.000E-03	1.000	2.14	4.50	1.04
L63	10.09	.00	2.000E-03	1.000	.33	.70	.23
L71	5.00	.00	3.000E-03	.001	.02	.00	.03
L71	6.72	.00	3.000E-03	.196	.07	.03	.08
L81	5.62	.00	2.000E-03	.024	.02	.00	.03
L81	7.57	.00	2.000E-03	.446	.09	.08	.08
R1	1.56	.78	5.000E+00	.000	.01	.00	.08
R2	1.91	.78	2.000E+00	.000	.02	.00	.12
BL1	3.98	.00	1.000E+00	.000	2.10	.00	4.01
R2	3.98	.00	1.000E+00	.000	2.10	.00	4.01
TL1	7.42	.78	1.000E+00	.561	26.01	30.60	25.98
TR1	5.86	.78	1.000E+00	.076	7.63	1.22	10.02
GAG	7.42	.00	1.000E+00	.395	39.23	32.50	36.41

PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP FLIGHT TYPE NO. 5 PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP

FLIGHT TYPE = FLIGHT TYPE 5
NUMBER OF FLIGHTS IN THE BLOCK = 3
PCT. TOTAL BLOCK DAMAGE THIS FLIGHT CAUSES: UNRET.= 44.15
RET.= 47.40
DURABILITY= 35.85
NUMBER OF SPECTRUM INPUTS DESCRIBING FLIGHT TYPE = 65

LABEL	FMAX	FMIN	CYCLES	RET.FAC.	PERCENT OF DA PER FLIGHT UNRETARDED	PERCENT OF DA PER FLIGHT RETARDED	PERCENT DURABILITY
T1	.82	.74	6.000E+02	.000	.00	.00	.00
T2	.90	.66	3.300E+02	.000	.00	.00	.03
T3	.20	.12	5.400E+01	.000	.00	.00	.00
T4	.22	.10	4.000E+00	.000	.00	.00	.00
T5	.23	.09	1.600E-02	.000	.00	.00	.00
T6	.25	.07	8.000E-03	.000	.00	.00	.00
L11	1.39	.00	3.000E-02	.000	.00	.00	.00
L11	1.87	.00	3.000E-02	.000	.00	.00	.00
L12	4.76	.00	8.000E-03	.000	.01	.00	.02
L13	3.20	.00	8.000E-03	.000	.00	.00	.00
L21	1.87	.00	9.000E-02	.000	.00	.00	.01
L21	2.53	.00	9.000E-02	.000	.00	.00	.02
L22	6.43	.00	2.200E-02	.134	.06	.01	.13
L23	4.32	.00	2.200E-02	.000	.01	.00	.03
L31	2.50	.00	1.960E-01	.000	.01	.00	.06
L31	3.36	.00	1.960E-01	.000	.03	.00	.12
L32	8.58	.00	5.000E-02	.853	.57	.53	.03
L33	5.76	.00	5.000E-02	.037	.09	.00	.20
L41	3.12	.00	2.300E-01	.000	.02	.00	.11
L41	4.21	.00	2.300E-01	.000	.09	.00	.30
L42	10.72	.00	5.600E-02	1.000	1.40	2.00	2.12
L43	7.20	.00	5.600E-02	.326	.28	.10	.49
L51	3.75	.00	2.240E-01	.000	.05	.00	.20
L51	5.03	.00	2.240E-01	.002	.21	.00	.54
L52	12.87	.00	5.600E-02	1.000	4.26	4.72	4.25
L53	6.65	.00	5.600E-02	.884	.66	.64	.95
L61	4.37	.00	2.140E-01	.000	.10	.00	.32
L61	5.89	.00	2.140E-01	.052	.41	.02	.91
L62	15.00	.00	5.600E-02	1.000	8.75	9.69	7.76
L63	10.09	.00	5.200E-02	1.000	1.26	1.40	1.56
L71	5.00	.00	1.420E-01	.001	.13	.00	.34
L71	6.72	.00	1.420E-01	.140	.51	.11	.97
L72	17.15	.00	3.600E-02	1.000	10.56	11.70	8.58
L73	11.53	.00	3.600E-02	1.000	1.63	1.81	1.79
L81	5.62	.00	9.200E-02	.024	.14	.00	.33
L81	7.57	.00	9.200E-02	.446	.58	.29	.96
L82	19.30	.00	2.200E-02	1.000	11.24	12.45	8.57
L83	12.97	.00	2.200E-02	1.000	1.74	1.92	1.72
L91	6.18	.00	5.600E-02	.091	.14	.01	.28
L91	8.31	.00	5.600E-02	.734	.55	.44	.02
L92	21.20	.00	1.400E-02	1.000	11.12	12.32	8.16
L93	14.25	.00	1.400E-02	1.000	1.72	1.90	1.58
L101	6.67	.00	3.000E-02	.233	.12	.03	.22
L101	9.24	.00	3.000E-02	1.000	.48	.53	.65
L102	23.59	.00	6.000E-03	1.000	10.50	11.63	7.48
L103	15.85	.00	8.000E-03	1.000	1.62	1.79	1.38
L111	7.50	.00	1.000E-02	.422	.11	.05	.18
L111	10.00	.00	1.000E-02	1.000	.43	.40	.94
L112	25.73	.00	4.000E-03	1.000	7.09	8.75	5.56
L113	17.29	.00	4.000E-03	1.000	1.22	1.35	.99
L121	8.12	.00	1.000E-02	.655	.09	.06	.13
L121	10.92	.00	1.000E-02	1.000	.35	.39	.41
L122	27.87	.00	2.000E-03	1.000	5.75	6.37	4.06
L123	18.73	.00	2.000E-03	1.000	.89	.90	.69
L131	8.82	.00	6.000E-03	.962	.08	.08	.11
L131	11.79	.00	6.000E-03	1.000	.30	.35	.33
L141	9.37	.00	2.000E-03	1.000	.03	.06	.05
L141	12.00	.00	1.000E-03	1.000	.07	.08	.07
A1	3.19	1.61	5.000E+00	.000	.04	.00	.26
A2	3.96	1.61	2.000E+00	.000	.09	.00	.40
BL1	3.98	.00	1.000E+00	.000	.31	.00	1.07
A2	3.98	.00	1.000E+00	.000	.31	.00	1.07
TL1	7.42	.78	1.000E+00	.561	3.79	2.36	6.93
TR1	5.06	.78	1.000E+00	.079	1.11	.09	2.60
GAG	7.42	.00	1.000E+00	.395	5.72	2.50	9.72

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APPENDIX B

SHEAR WEB ANALYSIS STRESS SPECTRUM

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FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF FLIGHT TYPE NO. 1 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF

FLIGHT TYPE = FLIGHT TYPE 1
NUMBER OF FLIGHTS IN THE BLOCK = 1
PCT. TOTAL BLOCK DAMAGE THIS FLIGHT CAUSES: UNRET.= 4.87
RET.= 4.90
DURABILITY= 4.99
NUMBER OF SPECTRUM INPUTS DESCRIBING FLIGHT TYPE = 25

LABEL	FMAX	FMIN	CYCLES	RET.FAC.	PERCENT OF DA PER FLIGHT UNRETARDED	PERCENT OF DA PER FLIGHT RETARDED	PERCENT DURABILITY
T1	.51	.46	5.000E+02	.000	.00	.00	.00
T2	.56	.41	1.650E+02	.000	.01	.00	.08
T3	.61	.36	2.700E+01	.000	.01	.00	.07
T4	.65	.31	2.000E+00	.000	.00	.00	.02
T5	.70	.27	9.000E-02	.000	.00	.00	.00
T6	.75	.22	4.000E-03	.000	.00	.00	.00
L11	1.06	-.06	3.120E-01	.000	.09	.00	.52
L12	2.12	.00	7.900E-02	.104	.44	.05	.28
L21	1.19	-.74	1.740E-01	.000	.08	.00	.43
L22	2.39	.00	4.300E-02	.280	.42	.12	.23
L31	1.59	-.99	1.030E-01	.000	.19	.00	.66
L32	3.19	.00	2.600E-02	1.000	.97	1.01	.37
L41	1.49	-1.24	5.200E-02	.037	.28	.01	.71
L42	3.98	.00	1.300E-02	1.000	1.39	1.44	.40
L51	2.38	-1.48	1.800E-02	.263	.22	.06	.45
L52	4.78	.00	4.000E-03	1.000	1.01	1.04	.23
L61	2.78	-1.74	6.000E-03	.092	.16	.11	.25
L62	5.58	.00	1.000E-03	1.000	.52	.54	.10
L71	3.17	-1.98	2.000E-03	1.000	.10	.10	.13
L81	3.57	-2.23	1.000E-03	1.000	.08	.09	.10
R1	.83	.48	5.000E+00	.000	.01	.00	.04
R2	1.17	.46	2.000E+00	.000	.09	.00	.16
RL1	1.64	.00	1.000E+00	.000	1.05	.00	1.49
TL1	3.22	.00	1.000E+00	1.000	39.26	40.61	14.83
GAG	3.22	-2.23	1.000E+00	1.000	53.00	54.83	70.44

FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF FLIGHT TYPE NO. 2 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF

FLIGHT TYPE = FLIGHT TYPE 2
NUMBER OF FLIGHTS IN THE BLOCK = 3
PCT. TOTAL BLOCK DAMAGE THIS FLIGHT CAUSES: UNRET.= 13.42
RET.= 14.69
DURABILITY= 14.97
NUMBER OF SPECTRUM INPUTS DESCRIBING FLIGHT TYPE = 25

LABEL	FMAX	FMIN	CYCLES	RET.FAC.	PERCENT OF DA PER FLIGHT UNRETARDED	PERCENT OF DA PER FLIGHT RETARDED	PERCENT DURABILITY
T1	.51	.46	5.000E+02	.000	.00	.00	.00
T2	.56	.41	1.650E+02	.000	.01	.00	.08
T3	.61	.36	2.700E+01	.000	.01	.00	.07
T4	.65	.31	2.000E+00	.000	.00	.00	.02
T5	.70	.27	9.000E-02	.000	.00	.00	.00
T6	.75	.22	4.000E-03	.000	.00	.00	.00
L11	1.06	-.66	3.120E-01	.000	.09	.00	.52
L12	2.12	.00	7.900E-02	.104	.44	.05	.28
L21	1.19	-.74	1.740E-01	.000	.08	.00	.43
L22	2.39	.00	4.300E-02	.280	.42	.12	.23
L31	1.59	-.99	1.030E-01	.000	.19	.00	.66
L32	3.19	.00	2.600E-02	1.000	.97	1.01	.37
L41	1.49	-1.24	5.200E-02	.037	.28	.01	.71
L42	3.98	.00	1.300E-02	1.000	1.39	1.44	.40
L51	2.38	-1.48	1.800E-02	.263	.22	.06	.45
L52	4.78	.00	4.000E-03	1.000	1.01	1.04	.23
L61	2.78	-1.74	6.000E-03	.592	.16	.11	.25
L62	5.58	.00	1.000E-03	1.000	.52	.54	.10
L71	3.17	-1.98	2.000E-03	1.000	.10	.10	.13
L81	3.57	-2.23	1.000E-03	1.000	.08	.09	.10
R1	.83	.48	5.000E+00	.000	.01	.00	.04
R2	1.17	.48	2.000E+00	.000	.09	.00	.16
RL1	1.64	.00	1.000E+00	.000	1.05	.00	1.49
TL1	3.22	.00	1.000E+00	1.000	39.26	40.61	14.83
GAG	3.22	-2.23	1.000E+00	1.000	53.00	54.83	70.44

FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF FLIGHT TYPE NO. 3 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF

FLIGHT TYPE = FLIGHT TYPE 3
NUMBER OF FLIGHTS IN THE BLOCK = 3

PCT. TOTAL BLOCK DAMAGE THIS FLIGHT CAUSES:	UNRET.=	25.37
	RET.=	25.31
	DURABILITY=	27.32

NUMBER OF SPECTRUM INPUTS DESCRIBING FLIGHT TYPE = 37

LABEL	FMAX	FMIN	CYCLES	RET.FAC.	PERCENT OF DA PER FLIGHT UNRETARDED	PERCENT OF DA PER FLIGHT RETARDED	PERCENT DURABILITY
T1	.42	.38	6.000E+02	.000	.00	.00	.00
T2	.46	.34	3.300E+02	.000	.01	.00	.05
T3	.16	.10	5.400E+01	.000	.00	.00	.00
T4	.18	.08	4.000E+00	.000	.00	.00	.00
T5	.19	.07	1.800E-01	.000	.00	.00	.00
T6	.30	.06	8.000E-03	.000	.00	.00	.00
L11	.66	-.55	1.500E-02	.000	.00	.00	.01
L12	1.77	.00	4.000E-03	.005	.01	.00	.00
L21	1.19	-.74	4.500E-02	.000	.01	.00	.06
L22	2.39	.00	1.100E-02	.280	.06	.02	.03
L31	1.59	-.99	9.800E-02	.000	.10	.00	.35
L32	3.19	.00	2.500E-02	1.000	.50	.56	.20
L41	1.99	-1.24	1.150E-01	.037	.33	.01	.06
L42	3.98	.00	2.800E-02	1.000	1.58	1.80	.48
L51	2.38	-1.48	1.120E-01	.263	.74	.22	1.53
L52	4.78	.00	2.800E-02	1.000	3.73	4.24	.90
L61	2.78	-1.74	1.070E-01	.692	1.47	1.15	2.47
L62	5.58	.00	2.600E-02	1.000	7.15	8.11	1.46
L71	3.17	-1.98	7.100E-02	1.000	1.80	2.05	2.55
L72	6.37	.00	1.800E-02	1.000	9.27	10.52	1.00
L81	3.57	-2.23	4.000E-02	1.000	2.04	2.32	2.46
L82	7.17	.00	1.100E-02	1.000	9.85	11.18	1.49
L91	3.92	-2.45	2.800E-02	1.000	1.93	2.19	2.06
L92	7.85	.00	7.000E-03	1.000	9.76	11.08	1.36
L101	4.37	-2.73	1.500E-02	1.000	1.72	1.95	1.59
L102	8.76	.00	4.000E-03	1.000	9.20	10.44	1.13
L111	4.76	-2.97	9.000E-03	1.000	1.54	1.75	1.27
L112	9.56	.00	2.000E-03	1.000	6.93	7.86	.70
L121	5.15	-3.22	5.000E-03	1.000	1.25	1.42	.93
L122	10.36	.00	1.000E-03	1.000	5.04	5.72	.52
L131	5.60	-3.50	3.000E-03	1.000	1.10	1.25	.76
L141	5.95	-3.72	1.000E-03	1.000	.49	.56	.30
R1	.80	.40	5.000E+00	.000	.01	.00	.04
R2	.90	.40	2.000E+00	.000	.02	.00	.05
GL1	1.37	.00	1.000E+00	.000	.37	.00	.46
TL1	2.08	.00	1.000E+00	.568	8.80	5.00	4.34
GAG	2.98	-3.72	1.000E+00	.529	13.19	7.91	60.00

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FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF FLIGHT TYPE NO. 4 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF

FLIGHT TYPE = FLIGHT TYPE 4
NUMBER OF FLIGHTS IN THE BLOCK = 5
PCT. TOTAL BLOCK DAMAGE THIS FLIGHT CAUSES: UNRET.= 11.67
RET.= 7.93
DURABILITY= 18.03
NUMBER OF SPECTRUM INPUTS DESCRIBING FLIGHT TYPE = 25

LABEL	FMAX	FMIN	CYCLES	RET.FAC.	PERCENT OF DA PER FLIGHT UNRETARDED	PERCENT OF DA PER FLIGHT RETARDED	PERCENT DURABILITY
T1	.42	.38	3.000E+02	.000	.00	.00	.00
T2	.46	.34	1.650E+02	.000	.01	.00	.06
T3	.50	.30	2.700E+01	.000	.01	.00	.05
T4	.55	.26	2.000E+00	.000	.00	.00	.01
T5	.59	.22	9.000E-02	.000	.00	.00	.00
T6	.63	.18	4.000E-03	.000	.00	.00	.00
L11	.88	-.55	6.240E-01	.000	.14	.00	.78
L12	1.77	.00	1.580E-01	.005	.72	.01	.42
L21	1.19	-.74	3.480E-01	.000	.32	.00	1.18
L22	2.39	.00	8.600E-02	.280	1.60	.75	.64
L31	1.59	-.99	2.060E-01	.000	.74	.00	1.84
L32	3.19	.00	5.200E-02	1.000	3.73	6.22	1.03
L41	1.99	-1.24	1.040E-01	.037	1.07	.07	1.97
L42	3.98	.00	2.600E-02	1.000	5.33	8.88	1.12
L51	2.38	-1.48	3.600E-02	.263	.66	.38	1.24
L52	4.78	.00	8.000E-03	1.000	3.86	6.44	.65
L61	2.78	-1.74	1.200E-02	.692	.60	.69	.70
L62	5.58	.00	2.000E-03	1.000	1.99	3.32	.28
L71	3.17	-1.98	3.000E-03	1.000	.28	.46	.27
L81	3.57	-2.23	2.000E-03	1.000	.32	.54	.27
R1	.80	.40	5.000E+00	.000	.04	.00	.09
R2	.99	.40	2.000E+00	.000	.08	.00	.13
SL1	1.37	.00	1.000E+00	.000	1.34	.00	1.11
TL1	2.08	.00	1.000E+00	.568	31.88	30.19	10.96
GAG	2.08	-2.23	1.000E+00	.560	45.07	42.07	75.21

FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF FLIGHT TYPE NO. 5 FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF

FLIGHT TYPE = FLIGHT TYPE5
NUMBER OF FLIGHTS IN THE BLOCK = 3
PCT. TOTAL BLOCK DAMAGE THIS FLIGHT CAUSES: UNRET.= 45.06
RET.= 47.18
DURABILITY= 54.69
NUMBER OF SPECTRUM INPUTS DESCRIBING FLIGHT TYPE = 37

LABEL	FMAX	FMIN	CYCLES	RET.FAC.	PERCENT OF DA PER FLIGHT UNRETARDED	PERCENT OF DA PER FLIGHT RETARDED	PERCENT DURABILITY
T1	.42	.38	6.000E+02	.000	.00	.00	.00
T2	.46	.34	3.300E+02	.000	.00	.00	.04
T3	.16	.10	5.400E+01	.000	.00	.00	.00
T4	.18	.08	4.000E+00	.000	.00	.00	.00
T5	.19	.07	1.800E-02	.000	.00	.00	.00
T6	.20	.06	4.000E-03	.000	.00	.00	.00
L11	.86	-.55	3.000E-02	.000	.00	.00	.01
L12	1.77	.00	8.000E-03	.005	.01	.00	.01
L21	1.19	-.74	9.000E-02	.000	.01	.00	.09
L22	2.39	.00	2.200E-02	.280	.06	.02	.05
L31	1.59	-.99	1.960E-01	.000	.11	.00	.55
L32	3.19	.00	5.000E-02	1.000	.56	.60	.31
L41	1.99	-1.24	2.300E-01	.037	.37	.01	1.30
L42	3.98	.00	5.600E-02	1.000	1.78	1.93	.75
L51	2.38	-1.48	2.240E-01	.263	.83	.24	2.40
L52	4.78	.00	5.600E-02	1.000	4.20	4.55	1.42
L61	2.78	-1.74	2.140E-01	.092	1.65	1.24	3.90
L62	5.58	.00	5.200E-02	1.000	8.05	8.71	2.20
L71	3.17	-1.98	1.420E-01	1.000	2.03	2.19	4.01
L72	6.37	.00	3.600E-02	1.000	10.44	11.28	2.52
L81	3.57	-2.23	9.200E-02	1.000	2.30	2.49	3.88
L82	7.17	.00	2.200E-02	1.000	11.10	12.00	2.35
L91	3.92	-2.45	5.600E-02	1.000	2.17	2.35	3.24
L92	7.88	.00	1.400E-02	1.000	11.00	11.89	2.10
L101	4.37	-2.73	5.000E-02	1.000	1.94	2.10	2.50
L102	8.76	.00	8.000E-03	1.000	10.36	11.20	1.78
L111	4.76	-2.97	1.800E-02	1.000	1.74	1.88	2.00
L112	9.56	.00	4.000E-03	1.000	7.80	8.43	1.23
L121	5.16	-3.22	1.000E-02	1.000	1.41	1.53	1.46
L122	10.36	.00	2.000E-03	1.000	5.68	6.14	.83
L131	5.06	-3.50	6.000E-03	1.000	1.24	1.35	1.10
L141	5.45	-3.72	2.000E-03	1.000	.55	.60	.48
R1	.26	.13	5.000E+00	.000	.00	.00	.00
R2	.32	.13	2.000E+00	.000	.00	.00	.00
SL1	1.37	.00	1.000E+00	.000	.21	.00	.35
TL1	2.08	.00	1.000E+00	.555	4.96	3.04	3.42
GAG	2.86	-3.72	1.000E+00	.529	7.42	4.24	53.55

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